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Manual of Ground-Water Quality Sampling Procedures

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MANUAL OF GROUND-WATER QUALITY SAMPLING PROCEDURES

by

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Recent environmental legislation has recognized the importance of ground water quality protection and the stresses that man's activities, especially waste disposal, place on this vital national resource. To provide a realistic assessment of current and potential pollution problems and a rational basis for ground water quality protection, it is necessary to collect representative samples from this remote and relatively inaccessible environment. This report presents some procedures currently utilized to sample ground water and subsurface earth materials for microbial and inorganic and organic chemical parameters.

In selecting a sampling procedure, a number of considerations are described based on the objectives of the sampling program, characteristics of pollutants, nature of pollution source, and hydrogeology of the area. Various techniques for constructing sampling wells and for withdrawing samples are described with advantages and disadvantages of each method listed. For situations where samples of subsurface earth materials are required to adequately assess ground-water quality threats, procedures are described for collecting, handling, and processing core samples. Finally, sample preservation, sample records, and chain of custody procedures are discussed.

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FOREWORD

A critical part of Environmental Protection Agency's research program is the development of accurate and reliable scientific data on which to base the Agency's environmental protection program. The Robert S. Kerr Environmental Research Laboratory conducts research on the nature, transport, fate and management of contaminants that may transverse the subsurface environment and threaten ground water quality.

The technology upon which to base the protection of ground water quality is perhaps a decade or more behind that of surface water. This results from a traditional lack of concern in the scientific and decision-making community and the complexity of the subsurface environment relative to its surface counterpart.

This report is a summary of several procedures currently used by the ground water community to collect ground water quality data. Some of the procedures described are in common usage while others are yet in the research or developmental stage. These procedures plus the concepts noted should provide federal, state, and local agencies as well as industry with a sound basis for the collection of reliable ground water data essential to the protection of this valuable natural resource.

Clinton W. Hall

Clinton W. Hall
Director
Robert S. Kerr Environmental Research Laboratory

ABSTRACT

Recent environmental legislation has recognized the importance of ground water quality protection and the stresses that man's activities, especially waste disposal, place on this vital national resource. To provide a realistic assessment of current and potential pollution problems and a rational basis for ground water quality protection, it is necessary to collect representative samples from this remote and relatively inaccessible environment. This report presents some procedures currently utilized to sample ground water and subsurface earth materials for microbial and inorganic and organic chemical parameters.

In selecting a sampling procedure, a number of considerations are described based on the objectives of the sampling program, characteristics of pollutants, nature of pollution source and hydrogeology of the area. Various techniques for constructing sampling wells and for withdrawing samples are described with advantages and disadvantages of each method listed. For situations where samples of subsurface earth materials are required to adequately assess ground water quality threats, procedures are described for collecting, handling, and processing core samples. Finally sample preservation, sample records, and chain of custody procedures are discussed.

The procedures described provide a basic capability for sampling subsurface environments. Additional research is needed, however, to further evaluate, improve and extend these capabilities, especially in sampling related to organic chemical parameters.

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Liberal use was also made of EPA Report 530/SW-611, "Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities", and the authors wish to express appreciation to EPA's Office of Solid Waste.

SECTION 1

INTRODUCTION

Ground water accounts for the base flow of all perennial streams, over 90 percent of the world's fresh water resources, and one half the drinking water in the United States, yet has traditionally received only token scientific attention. Although surface and ground waters are inseparable parts of the same hydrologic system with the waters of each flowing alternately between the two components, water resource planners have often considered them as separate entities.

The Safe Drinking Water Act (PL 93-523) of 1974 has done much to rectify this neglect by recognizing ground water as a major source of drinking water and establishing standards of ground water quality protection. This Act plus subsequent legislation, the Toxic Substances Control Act (PL 94-469) and the Resource Conservation and Recovery Act (PL 94-580) further recognizes that ground water quality is being increasingly threatened by various human activities, particularly the disposal of waste materials to the land.

In order to assess the impact of such activities on ground water quality and, hence, to provide a rational basis for its protection, the behavior of pollutants in the subsurface and the processes governing this behavior must be evaluated. However, many water resource planners, inexperienced in ground water investigations, are learning that techniques applicable to surface waters do not necessarily apply to ground water.

Methods of collecting a representative ground water sample are much more difficult and expensive in this often remote and relatively inaccessible environment. The subsurface is an extremely complex system subject to extensive physical, chemical and biological changes within small vertical and horizontal distances.

Chemical and microbial parameters, such as BOD and coliforms traditionally used to indicate pollution of surface waters, have limited, if any, value in describing the water quality of a ground water aquifer.

The purpose of this manual is to provide guidance and suggested methods of subsurface sampling for various typical ground water quality investigations. Although the great variability of hydrogeological conditions precludes identification of typical sites, it is possible to identify some basic fundamentals of subsurface sampling that may be used or modified to fit the unique conditions involved.

SECTION 2

OBJECTIVES OF SAMPLING

A monitoring well samples a very small part of an aquifer horizontally and in many cases, vertically. Unlike its surface counterpart where a sample can be arbitrarily taken at any point in the system, moving a ground water sampling point implies the installation of additional monitoring wells. Because of the difficulty and expense, it is essential that sampling objectives be firmly established well in advance of field activities. These objectives will dictate the parameters to be measured, the necessary reliability of the water quality data, and analytical methodology and thence the sampling procedures necessary to meet these objectives.

If the objective is simply to determine the presence or absence of a conservative pollutant in a particular water supply, it is simple and relatively inexpensive to collect a sample at a water tap. However, if the objective is to define the horizontal and vertical distribution of an organic pollutant or pollutants and predict the eventual fate, then soil cores, monitoring wells and special sampling equipment may increase efforts and cost several orders of magnitude.

In the former case, the purpose of the sample collection activity is known and limited in scope. In the latter case, there is a need to be concerned not with point data as an end in itself, but as a component of a network approach wherein information on the ground water system is developed as a basis for extrapolating information to areas where samples were not collected and/or for predicting the effects of natural and manmade stresses on the subsurface system (1).

SECTION 3

PRELIMINARY EVALUATIONS

CHARACTERISTICS OF POLLUTANT

The unstable nature of many chemical, physical, and microbial constituents in ground water and subsurface materials limit the sample collection and analysis options. Ground water normally moves very slowly. This results in a slow rate of change in water quality parameters. However, the subsurface is a unique heterogenous environment and maintaining the integrity of a sample from the time of sampling to the time of analysis is often a very difficult process. Because the physical, chemical, and microbial aspects of the environment are so closely interrelated it is very difficult to deal with one aspect without affecting the others. However, in selecting ground water sampling procedures, there are definite aspects of each that must be considered to maintain sample integrity.

Ground waters are usually well insulated, therefore temperature fluctuations are minimal in their natural environment; however, once removed to the surface, temperature may change very rapidly. Temperature may influence many aspects of water quality. Kinetically slow processes such as gas exchange or solid/solution reactions may be affected since many rates double with each 10°C rise in temperature. In an irreversible reaction, higher temperatures will decrease the time required to produce the final products. In a reversible reaction, temperature influences both the length of time required to reach equilibrium, and the proportion of the reactants and products at equilibrium conditions. Also, temperature affects microbial growth. In general, microbial metabolic activity is approximately doubled for each 10°C rise in temperature until a temperature is reached at which the rate of thermal denaturation of enzyme proteins exceeds the rate of thermal stimulation of enzyme reaction rates.

Many ions normally present in only trace amounts in normal waters may not remain unchanged when sampled because of chemical and physical reactions such as oxidation, precipitation, adsorption and ion exchange. Coprecipitation may also reduce the concentrations of these constituents in solution. Iron is a particularly troublesome component in natural waters because of its tendency to precipitate from solution and to coprecipitate other ions. Precipitation is generally enhanced in solutions where the pH is high and the temperature is relatively low. Because iron is precipitated as the hydroxide, it is seldom one of the major constituents in water. The metal, however, occurs in water in both the ferrous and ferric states. Ferrous iron in solution is unstable in the presence of oxygen.

$$2FE^{++} + 4HCO_3^- + H_2O + \frac{1}{2}O_2 \rightleftharpoons Fe(OH)_3 + 4CO_2$$

If the sample is subjected to a strong reducing environment, the reaction may reverse, and the resultant solution may contain large quantities of ferrous iron. The solubility of iron in natural water is governed by pH, Eh, and the concentration of organic ligands, as well as HCO_3^- and $S^=$ ions.

Carbonates and bicarbonates are particularly susceptible to an equilibrium shift if samples are taken in plastic bottles. Most plastics diffuse CO_2 thereby creating an equilibrium shift.

$$CO_2(g) + H_2O \rightleftharpoons H_2CO_3\ (aq.)$$

$$H_2CO_3\ (aq.) \rightleftharpoons HCO_3^- + H^+$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^=$$

A quick analysis is required to accurately determine these ionic species before changes are made.

The percentage concentrations of the various components of the nitrogen cycle may change rapidly as a result of biological activity which also greatly influences the conversion of organic phosphates to ortho-phosphate.

Water containing dissolved sulfides readily loses H_2S, particularly if the pH of the sample is low. If the pH of the sample is high, sulfide ions may be lost by oxidation.

Many water samples may contain solid colloidal particles showing a marked tendency to lose certain components while retaining others. When this occurs, the components that are lost are replaced with similar species from solution. This phenomenon of ion-exchange is both cationic and anionic; however, cation exchange is more prevalent in ground water samples since most anions are very water soluble (Cl^-, NO_3^-, $SO_4^=$). Ion-exchange of sorbed species for hydrogen ions is particularly enhanced by acid fixation before filtration, therefore, care should be exercised in this regard.

Collection of ground water samples for the identification of specific organic compounds is a relatively new, tedious and complex process and differs substantially from routine methods used for inorganic compounds. Analyses of organic compounds are both expensive and time consuming. Yet the thousands of dollars spent for the evaluation of a suite of samples are completely wasted if the samples are not properly collected and stored.

Organic compounds in the parts per billion range may be significant to human health in contrast to the more innocuous inorganic compounds. Such considerations combined with the great complexity of these compounds accentuate the sampling problems associated with adsorption, contamination and volatility. Materials from which pumps, samplers, discharge lines, storage containers and well casings are constructed must receive careful consideration. Most of the common metals and plastics either contaminate water samples or remove substances from them. Metals may strongly adsorb organic compounds and there is the possibility of reactions catalyzed by metal surfaces. A compounding problem is the presence of lubricants derived from pumps and joint compounds. Many plastics adsorb organic contaminants and also bleed other compounds directly from their surfaces or, particularly, from the cementing agents (solvent) used to join pipe sections. Cemented joints should be avoided in any plastic materials used in sampling (3).

Sampling equipment should be constructed with materials that have the least potential for affecting the sample. Chief among these is glass with Teflon a close second and stainless steel probably third. The least desirable material is rubber. Unfortunately, detailed experimental data on the potential reactions between the materials and the wide range of organic compounds that serve as real or potential ground-water contaminants are simply not available.

NATURE OF POSSIBLE POLLUTION SOURCE

The area of consideration, the time available for monitoring, and potential concentration levels of pollutants all influence the sampling procedures selected. A regional or large area monitoring program may permit the use of existing wells, springs or even the baseflow of streams if these systems are compatible with the parameters of interest. If time is critical, existing sampling locations may be the only alternative. However, if the possible pollution source is relatively small, such as a landfill or lagoon, or if pollutant concentrations may be very low, such as with organics, special monitoring wells will almost surely be necessary. The number and location of additional wells needed depends on the purpose of monitoring, aquifer characteristics, and mobility of pollutants in the aquifer.

If the potential contamination source is above the water table, it may be necessary to sample the unsaturated zone to get a true picture of the threat to ground water. With the exception of chlorides, and to a lesser extent nitrates and sulfates, most pollutants can be sorbed to materials in the unsaturated zone and removed to some extent under favorable conditions (2). Therefore, it is possible to sample the ground water beneath a waste source for years and observe no contamination. This can give a false sense of security when actually pollutants are still moving very slowly through the unsaturated profile toward the ground water.

Considerable future sampling of ground water will relate to pollution or potential pollution resulting from hazardous waste disposal. Both soils and ground water in many areas may be contaminated to the extent that construction of monitoring wells and collection of samples may be hazardous to the health of workers involved. Such considerations, where applicable, should be an integral part of the process of selecting sampling procedures.

HYDROGEOLOGIC DATA

Geologic factors relate chiefly to geologic formations and their water-bearing properties, and hydrologic factors relate to the movement of water in the formations.

Knowledge of the hydrogeologic framework is important from two standpoints: (1) prediction of ground-water movement, and (2) geochemical considerations which affect the quality of ground water. The geologic framework includes lithology, texture, structure, and mineralogy, and the distribution of the materials through which ground water flows. The hydraulic properties of the earth materials depend upon their origin and lithology, as well as the subsequent stresses to which the materials have been subjected. Ground-water movement depends upon the effective permeability and the hydraulic gradient within an aquifer. Permeability is related to the nature, size and degree of interconnection of pores, fissures, joints, and other openings.

Prior to initiating any field work, all existing geologic and hydrologic data should be collected, compiled and interpreted. Data that may be available include: geologic maps, cross-sections, aerial photographs, and an array of water-well data including location, date drilled, depth, name of driller, water level and date, well completion methods, use of well, electric or radioactivity logs, or other geophysical data, formation samples, pumping test(s) and water-quality data. After compiling and thoroughly reviewing the collected data, the investigator can properly plan the type of investigation needed, including the data necessary to fill the gaps and the sampling necessary (parameters, frequency and locations(s)).

Water-level measurements are important basic preliminary data often used in selecting ground-water sampling sites, equipment and procedures. Water-level data can be obtained from wells, piezometers, or from surface-water manifestations of the ground water system such as springs, lakes, and streams. The depth to water may determine the type of pumps or samplers used and procedures and cost of constructing monitoring wells. Water-level contours drawn from static levels in wells penetrating the same aquifer can be used to make a preliminary determination of gross direction of flow. Note that nearby pumping wells or other artificial discharges or recharges may alter the natural gradient.

SECTION 4

HYDROGEOLOGIC CONSIDERATIONS

A positive sample from a monitoring well may prove the presence of contamination in the ground water, providing the integrity of the well and sampling procedure are intact, but a negative sample does not necessarily prove the absence of contamination in the aquifer. The heterogeneous nature of subsurface environments makes the location of sampling points a complicated and unpredictable science when trying to intercept a pollutant plume. Hydrogeologic conditions are site specific and it is impossible to prescribe standard locations for sampling points that would be applicable to all sites. In an aquifer with intergranular porosity, such as sands, gravels, sandstones and silts, water occurs in interconnected void spaces between individual particles of aquifer material. Some simplified "typical" flow patterns are illustrated in Figures 1 and 2. It is readily apparent that horizontal location of a monitoring well in relation to the pollutant source determines whether or not contaminated water is intercepted. Further, vertical location of the well screen and other well construction aspects also affect the quality of a sample collected from the well. Should the well screen be located above or below the zone of contamination, and assuming proper seals are located above and below the screen, samples from this well will very likely indicate no contamination unless it is pumped sufficiently to change the ground water flow pattern. On the other hand, if the well screen is not properly sealed from other subsurface zones or if the entire saturated thickness is screened, samples from the well may represent a composite of water from several different zones and concentrations will not be representative of any. Furthermore, such well construction may provide a conduit for the movement of contamination from one zone to another.

As noted previously, gross ground water flow patterns can be developed from water level contours. However, the actual movement of a plume may be somewhat more complex. For example, in a geologic environment such as alluvium or terrace deposits involving intergranular permeabilities, the shape of the plume may be controlled by abrupt changes in permeabilities such as the channel gravels as shown in Figure 3. Such changes in permeability are common in river-deposited geologic formations and can greatly affect the shape and rate of movement of pollution plumes.

The hydrogeology is further complicated by the different flow patterns of different pollutants. Ground water contaminated with a dense pollutant such as chloride creates a plume that tends to migrate to the base of the aquifer. Conversely, lighter pollutants such as hydrocarbons tend to "float" near the top of the saturated zone. In addition, different pollutants move through the subsurface at different rates relative to the rate of water movement because

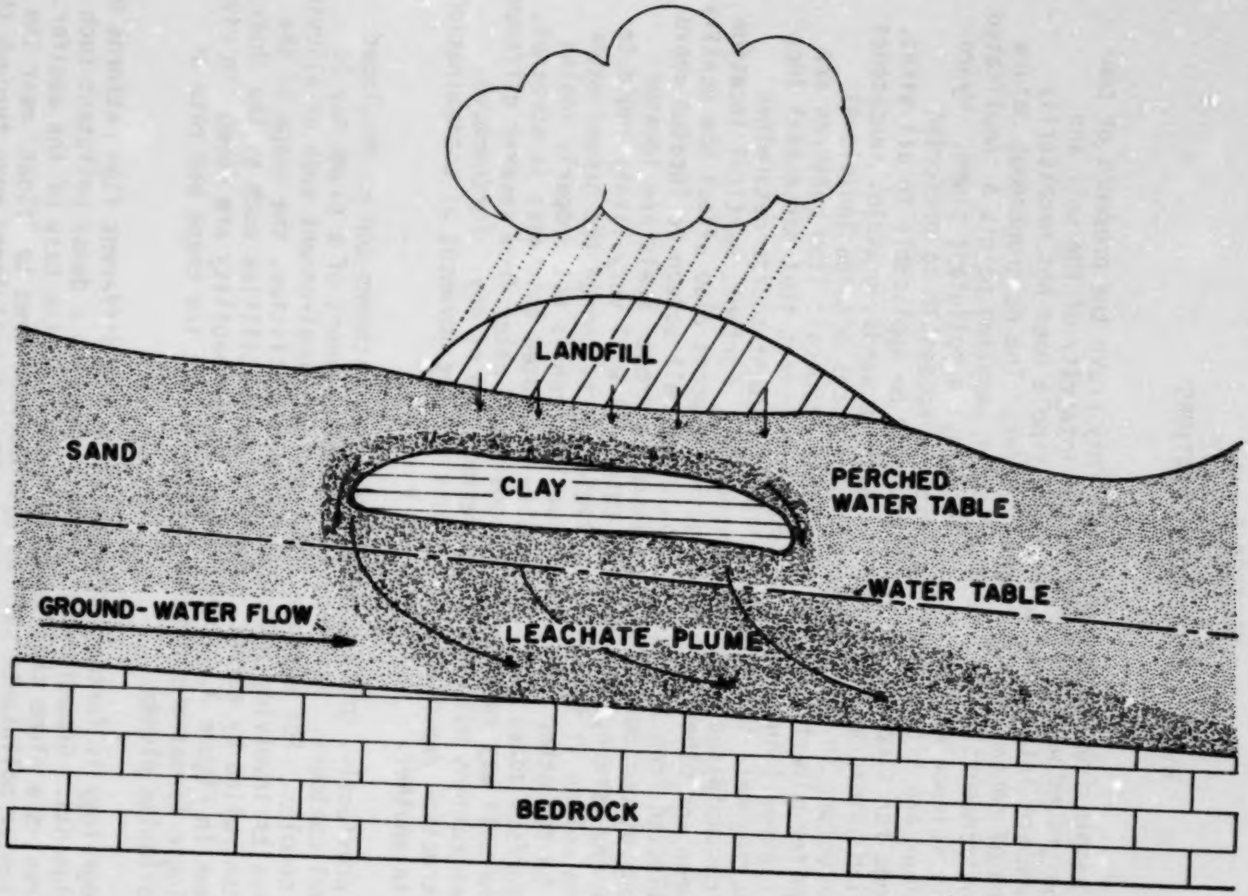

LANDFILL
SAND
CLAY
PERCHED WATER TABLE
WATER TABLE
GROUND-WATER FLOW
LEACHATE PLUME
BEDROCK

Figure 1. Permeable Sand Layer Underlain by a Clay Layer - The water table is deep. Leachate percolates downward under the landfill, forming a perched water table before finally reaching the actual water table. (2)

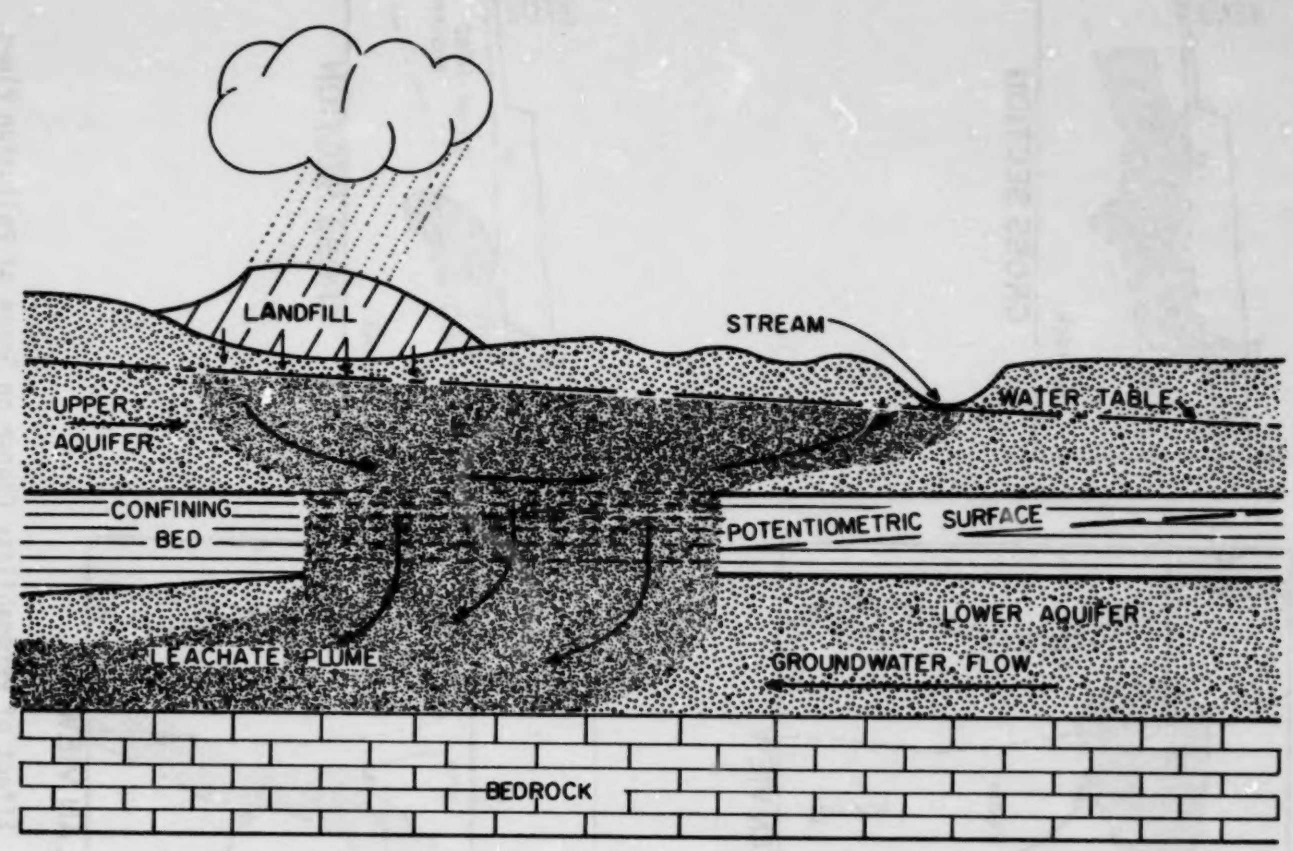

LANDFILL
STREAM
WATER TABLE
UPPER AQUIFER
CONFINING BED
POTENTIOMETRIC SURFACE
LOWER AQUIFER
LEACHATE PLUME
GROUNDWATER FLOW
BEDROCK

Figure 2. Two-Aquifer System with Opposite Flow Directions. Leachate first moves into and flows with the ground water in the upper aquifer. Some of the leachate eventually moves through the confining bed into the lower aquifer where it flows back beneath the landfill and away in the other direction. (2)

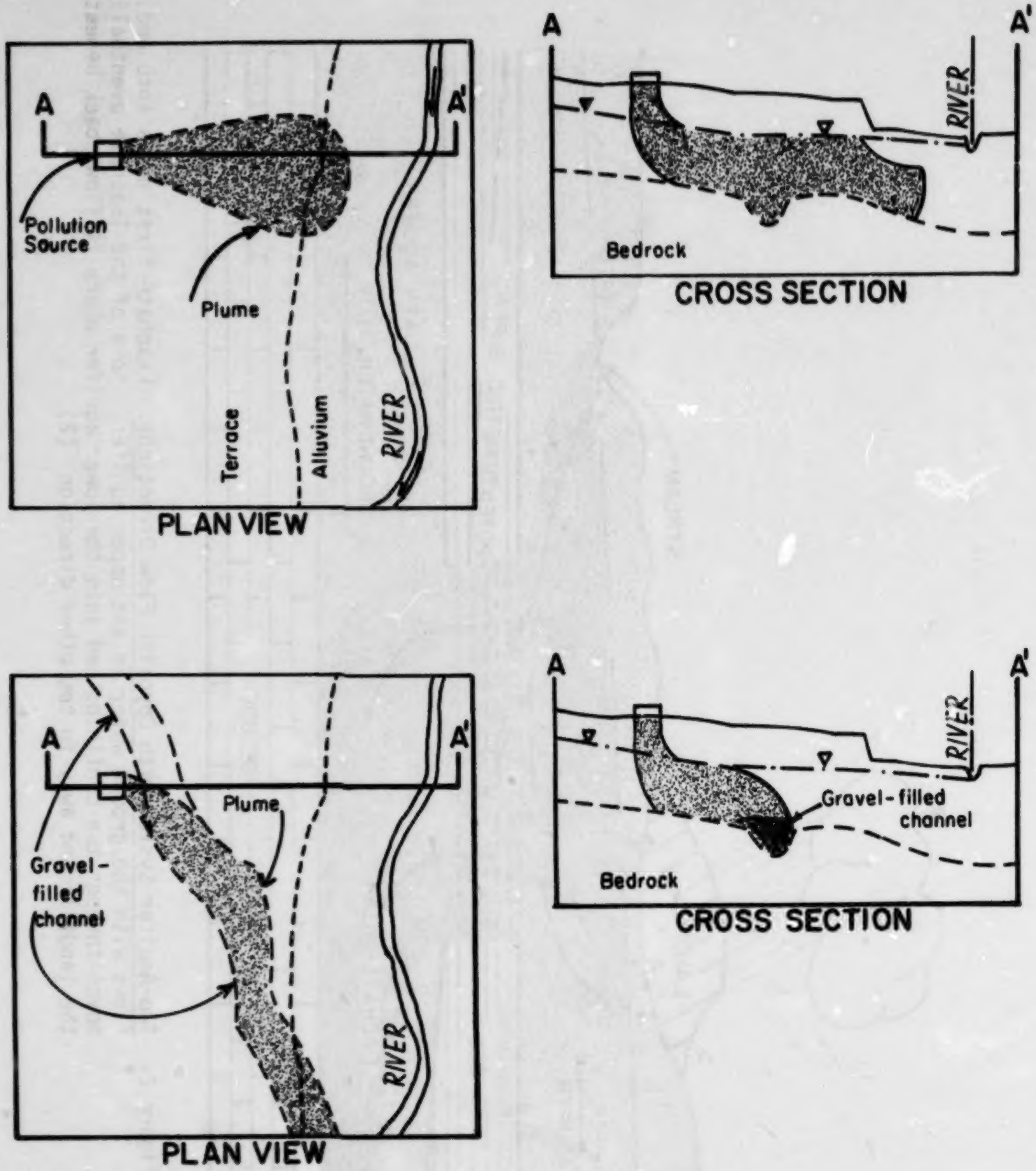

A
A'
Pollution Source
Plume
Terrace
Alluvium
RIVER
PLAN VIEW
A
A'
RIVER
Bedrock
CROSS SECTION
A
A'
Gravel-filled channel
Plume
RIVER
PLAN VIEW
A
A'
RIVER
Gravel-filled channel
Bedrock
CROSS SECTION

Figure 3. Effect of Permeability Change on Shape of Pollution Plume

of sorption, desorption, ion-exchange and biodegradation. Therefore, points of maximum concentration of the different pollutants along the ground water flow path will probably vary considerably.

Ground-water flow patterns are even less predictable in fractured rock or solution porosity aquifers than in aquifers with intergranular porosity. Flow patterns are generally controlled by fracture patterns such as those illustrated in Figures 4 and 5. Obviously, the problem in locating monitoring wells in such geology is to intercept fractures or solution channels that are hydraulically connected to the source of contamination. It is possible in many formations of this type to drill a well that is dry and move only a few feet away and drill another that has plenty of water. However, neither well may be hydraulically connected to a source of pollution only a few feet away.

In some fractured rock formations where caving is not a problem it is possible to complete a monitoring well as open hole without using a well screen. In most such wells it is advisable, however, to install casing (grouted in place) to at least the depth planned to set the pump. Care must be exercised especially in fractured rock formations such as limestone to maintain the depth-specific factor for monitoring wells. Wells with much open hole may intercept several fractured zones resulting in intercommunication between layers and sampling of mixed waters. This potential problem is illustrated in Figure 6.

In spite of the complexity, and in lieu of a detailed hydrogeologic study there are some basic guidelines that can be used in locating monitoring wells based on the considerations noted previously. A more detailed examination of locating monitoring wells for a landfill is described in EPA Report EPA-530/SW-611, "Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities" (2).

A necessary component of any ground water monitoring program is background sampling. Occasionally, it is possible to sample the ground-water quality of an area before a source of contamination is introduced. This is desirable and may become more common in the future as ground-water quality protection becomes a greater part of normal operations. In most instances, however, a potential source of contamination is already a reality and the objective is to collect a sample for comparison that is out of the influence of that source. Another consideration is that an analysis of an earlier sample may not have included a parameter that is of current interest or that analytical capabilities may have improved for certain parameters in the meantime.

One recommended monitoring method for detecting contamination at landfills is location of a background well upgradient from the landfill and a minimum of three wells downgradient and at an angle perpendicular to ground-water flow, penetrating the entire saturated thickness of the aquifer. Such an arrangement is illustrated in Figure 7 and is applicable to most potential point sources of contamination.

If there is adequate reason to suggest that contamination has already occurred and the objective is to define the pollutant plume, this remains a reasonable initial approach. However, it is extremely important to locate

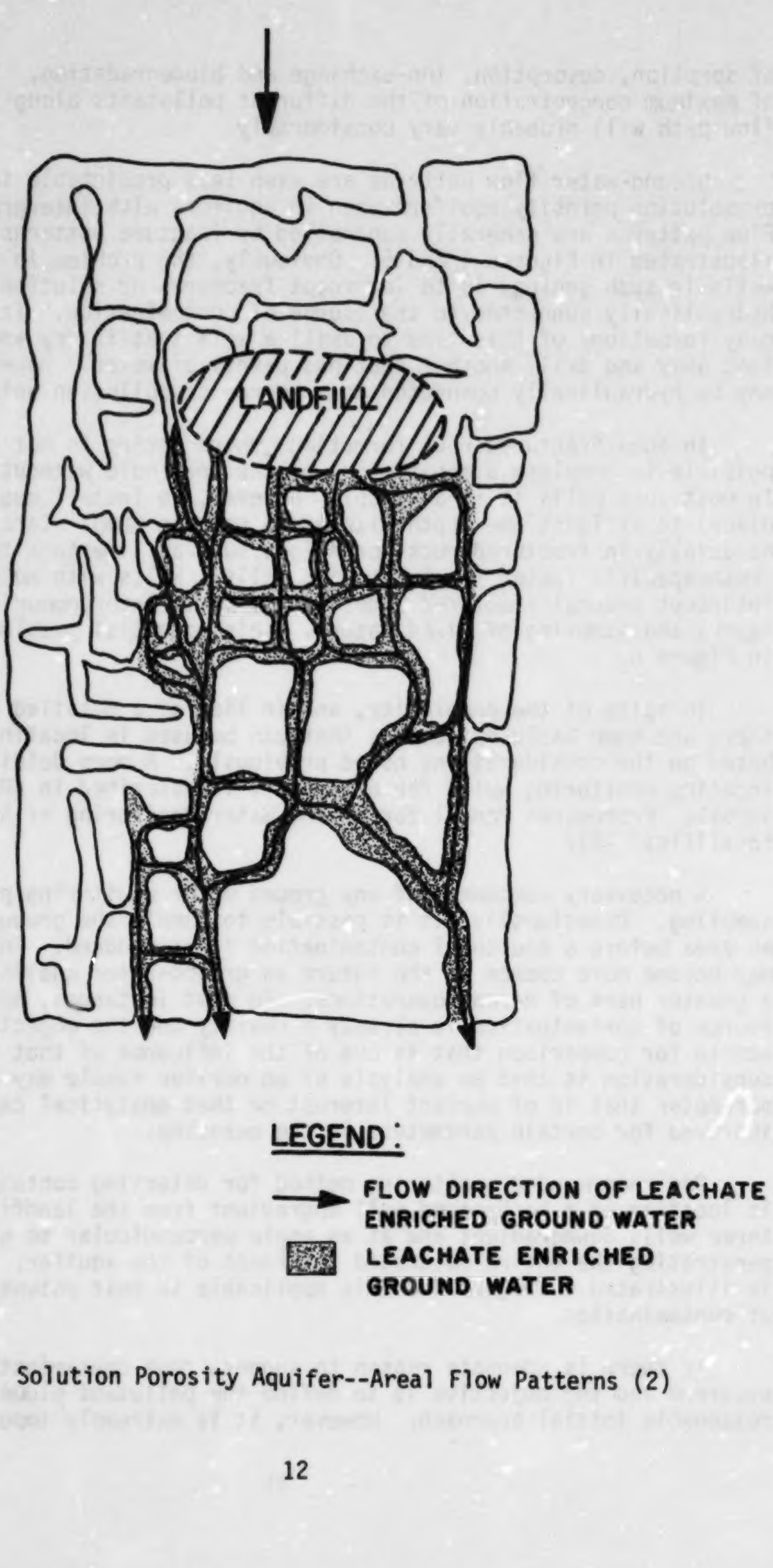

LANDFILL
LEGEND:
FLOW DIRECTION OF LEACHATE ENRICHED GROUND WATER
LEACHATE ENRICHED GROUND WATER

Figure 4. Solution Porosity Aquifer--Areal Flow Patterns (2)

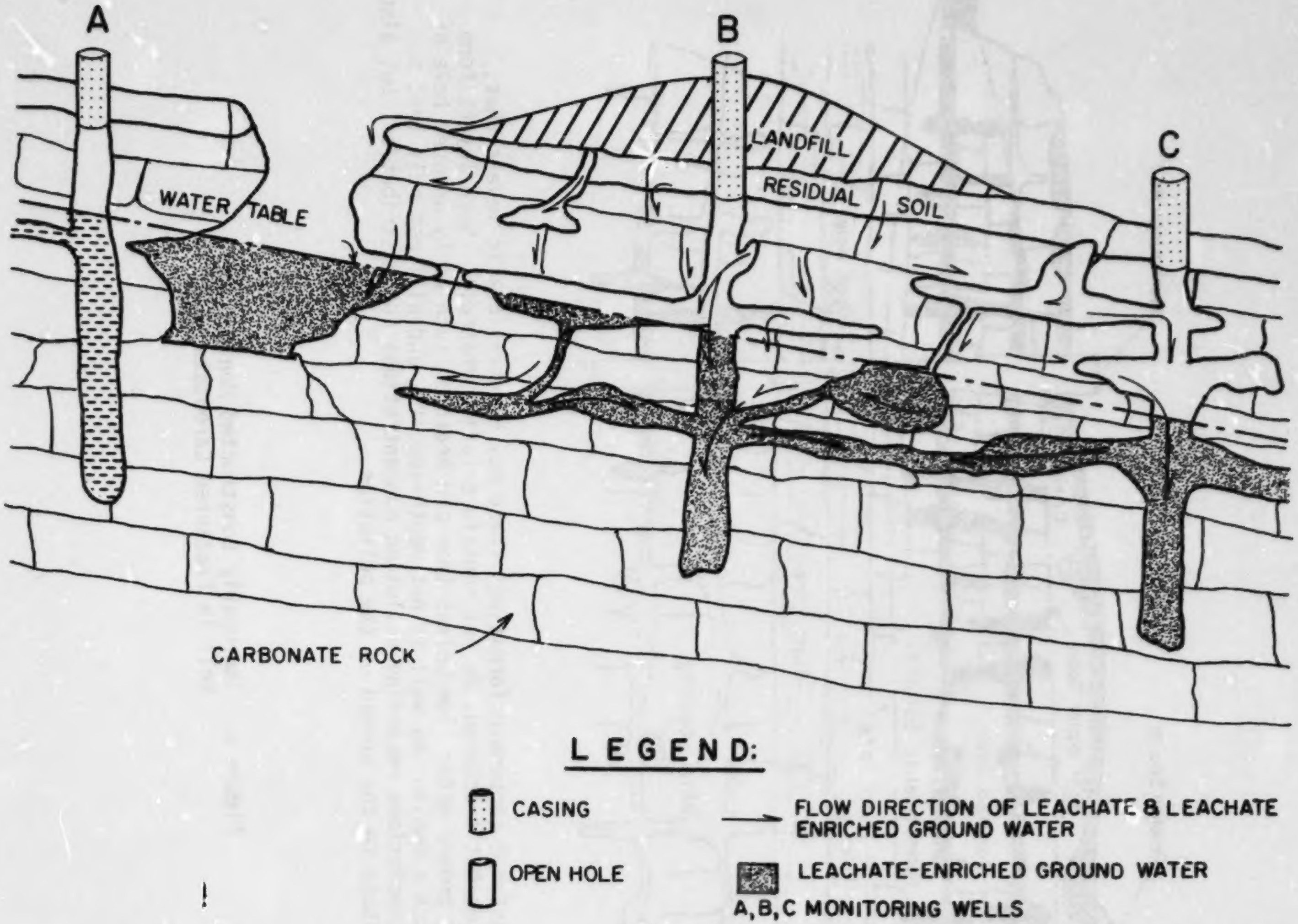
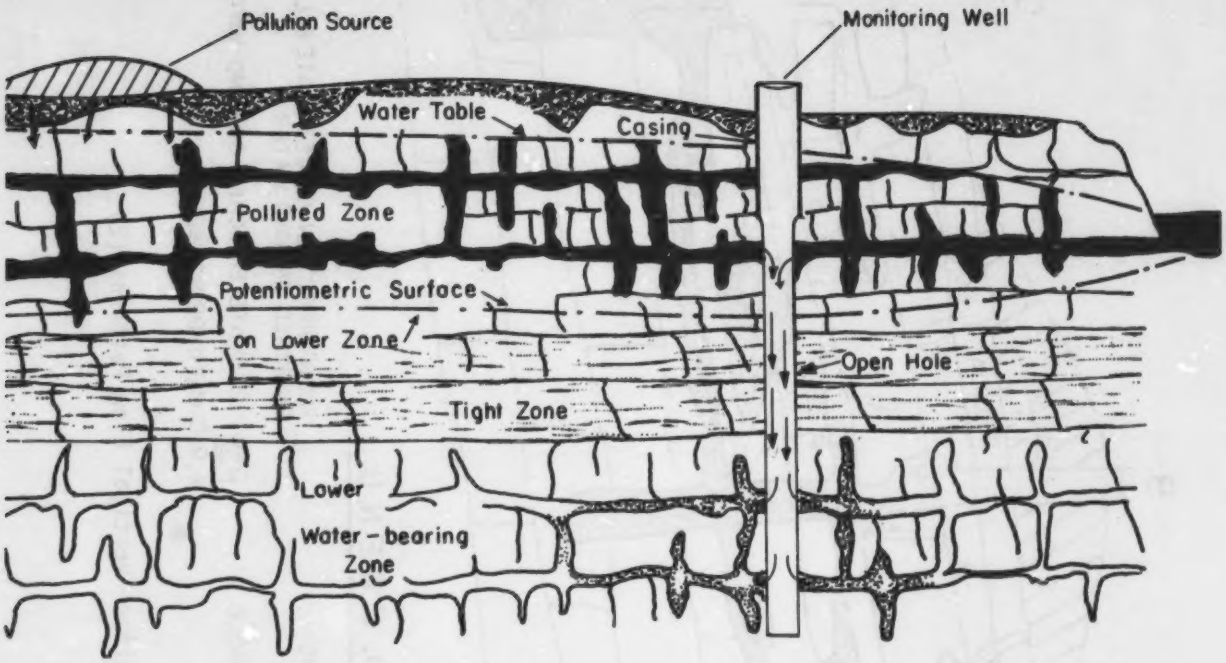

A
B
C
LANDFILL
RESIDUAL SOIL
WATER TABLE
CARBONATE ROCK
LEGEND:
CASING
OPEN HOLE
FLOW DIRECTION OF LEACHATE & LEACHATE ENRICHED GROUND WATER
LEACHATE-ENRICHED GROUND WATER
A, B, C MONITORING WELLS

Figure 5. Solution Porosity Aquifer--Vertical Flow Patterns (2)


Pollution Source
Monitoring Well
Water Table
Casing
Polluted Zone
Potentiometric Surface
on Lower Zone
Open Hole
Tight Zone
Lower
Water - bearing
Zone

Even in fractured carbonate formations there may be stratigrafic layers that, although somewhat fractured, do not contain solution channels. Such layers form barriers to ground water flow unless they are breached such as by an open hole of a well. Such a monitoring well is not depth-specific and will not only lead to erroneous conclusions regarding pollution concentrations and distribution, but also will contribute to the spread of the pollution.

Figure 6. Improperly Constructed Monitoring Well in Fractured Carbonate Rock

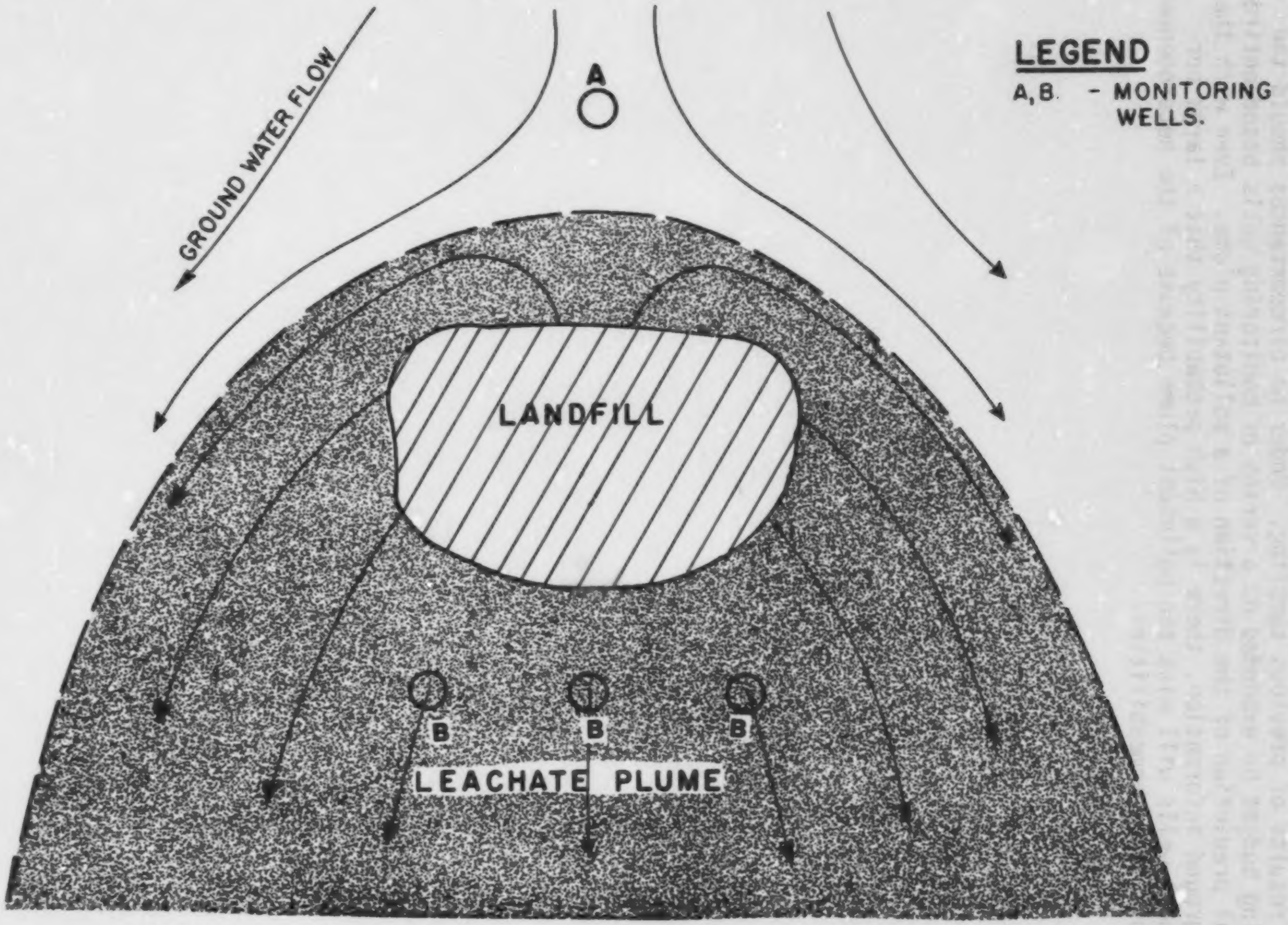

LEGEND
A,B - MONITORING WELLS.
GROUND WATER FLOW
A
LANDFILL
B
B
B
LEACHATE PLUME

Figure 7. Idealized Monitoring Network (2)

subsequent monitoring wells one at a time, sample, and base succeeding well locations on results of previous sampling. Under no circumstances should the entire drilling budget be expended on a series of monitoring wells based entirely on the initial prediction of the direction of a pollutant plume. Even with the best of background information, there is a high probability that a large percentage of these wells will miss the pollutant plume because of the heterogeneous nature of subsurface permeabilities.

SECTION 5

CONSTRUCTION OF MONITORING WELLS

The success of a ground-water monitoring program depends on numerous factors; however, the location, design, and construction of the monitoring wells is usually the most costly and non-repeatable factor. Hence, it is extremely important that the well construction be accomplished properly at the outset.

The primary objectives of monitoring wells are:
(a) to provide access to ground water
(b) to determine which pollutants are present in the ground water and the concentrations.
(c) to determine the areal and vertical distribution of pollutants.

In order to accomplish these objectives in the most competent and cost-effective manner, consideration must be given the proper well design and construction method that will best fit the specific objectives and the hydrogeologic conditions.

GENERAL REQUIREMENTS

Location

The general criteria for locating monitoring wells are discussed in the preceding section. Occasionally a location which is highly desired from groundwater flow criteria presents unusual problems in design and construction of the monitoring well. The effect that the location may have on well design and construction can best be appreciated following the detailed discussions on drilling methods and design criteria.

Diameter

The diameter of the casing for monitoring wells should be just sufficient to allow the sampling tool (bailer or pump) to be lowered into the well to the desired depth. The diameter of the hole into which the casing is placed must be at least sufficiently large for the casing to fit and in many cases must be at least 2 inches larger to permit placement of a grout seal around the outside of the casing.

Casings and/or holes drilled much larger than the necessary minimum can, in fact, have undesired effects on the data. For example, in formations of very low permeability the excessive storage in an unnecessarily large boring can cause the water level inside the boring to be erroneously low for days or even weeks. Also, because it is usually necessary to remove water standing in the well before taking a sample of the formation water, excessive storage can complicate the water sampling procedure.

Depth

The intake part of a monitoring well should be depth-discrete. That part of the well, the screen or other openings, through which water enters the well or casing should be limited to a specific depth range.

Water supply wells that may exist in an area to be monitored are often used as sampling points. Substantial care must be exercised when this is done and the results are often questionable. Water-supply wells are constructed to produce a given quantity of water, hence, they may be screened throughout a thick aquifer, through several permeable layers of an aquifer, or sometimes through two or more aquifers or discrete water-bearing layers. When this situation exists, it is probable that the hydrostatic heads are different between different layers. Under non-pumping conditions this interconnection permits water from the layer with the higher head to flow through the well and into the formation with the lower head. This can occur between layers of different permeability separated by only a few feet of low permeability material. This condition can, of course, have substantial effect on the concentration of a pollutant obtained by pumping for a short time before sampling.

Therefore, it is important that monitoring wells be constructed to be depth-discrete and to sample only from one specific layer without interconnection to other layers. In order to assure that this depth-discrete requirement is met, provisions for placing cement grout above and, if necessary, below the well screen on the outside of the casing must be made in the design of the wells.

Commonly (especially when sampling for contaminants lighter than water) it is desirable to sample at the water table, or top of the saturated zone in an unconfined aquifer. The screen or intake part of the well should then extend from a few feet above to a few feet below the anticipated position of the water table to allow for future water-table fluctuations. Often, under semi-confined aquifer conditions, the water will rise in the well above the top of the more permeable layer and above the top of an improperly positioned screen. Care must be exercised in these cases to extend the screen high enough to be above the water level in the formation; otherwise, light organics or other contaminants could be undetected or at least not properly quantified.

On the other hand, a contaminant can migrate along fairly restricted pathways and go undetected by depth discrete wells which are not completed at the proper depth. This danger is particularly present in a geologic environment of highly stratified formations, and in fractured rock formations.

Intake Portion of Monitoring Wells

That part of the well through which water enters the casing must be properly constructed and developed to avoid subsequent sampling problems. Commercially made well screens used in water-supply wells are recommended for most monitoring wells even though well efficiency is not a primary concern. Other choices are sawed or torchcut slots in the well casing to let the water flow in.

Design criteria for the intake part of the well are:

(a) The screen or intake part should have sufficient open area to permit the easy inflow of water from the formation.
(b) The slot openings should be just small enough to keep most of the natural formation out, but as large as possible to allow easy flow of water.
(c) The well should be developed.

Well Casings

As noted earlier, sampling equipment, including well casings, should be constructed of materials that have the least potential for affecting the quality parameters of the sample. The usual dilemma for the field investigator is the relation between cost and accuracy. Obviously, PVC is far less costly than Teflon, a major consideration when contemplating well construction for a major ground water monitoring effort. On the other hand, bleeding of organic constituents from PVC cements, as well as adsorption, poses a significant potential for affecting the quality of samples where the contaminants under consideration may be in the parts per billion range.

In many situations, it may be realistic to compromise some accuracy with cost, particularly in regard to casing materials used in well construction. For example, if the major contaminants are already defined and they do not include substances which might bleed from PVC or cemented joints, it might be reasonable to use wells cased with the less expensive and readily obtainable PVC. Or, wells constructed of less than optimum materials might be used with a reasonable level of confidence for sampling if at least one identically-constructed well was available in a nearby, uncontaminated part of the aquifer to provide ground water samples for use as "blanks". Obviously, such a "blank" will not address the problems of adsorption on the casing material nor leaching of casing material induced by contaminants in the ground water. Careful consideration is required in each individual case, and the analytical laboratory should be fully aware of construction materials used.

Care must be given to preparation of the casing and well screens prior to installation. As a minimum, both should be washed with a detergent and rinsed thoroughly with clean water. Care should also be taken that these and other sampling materials are protected from contamination by using some type of ground cover such as plastic sheeting for temporary storage in the work area.

DRILLING METHODS

Selection of the drilling method best suited for a particular job is based on the following factors in order of importance:

(1) Hydrogeologic Environment
    (a) Type(s) of formation(s)
    (b) Depth of drilling
    (c) Depth of desired screen setting below water table

(2) Types of pollutants expected
(3) Location of drilling site - dry land, or inside a lagoon
(4) Design of monitoring well desired
(5) Availability of drilling equipment

The principles of operation, advantages and disadvantages of the more common types of drilling techniques suitable for constructing ground-water monitoring wells are discussed as follows.

Mud Rotary

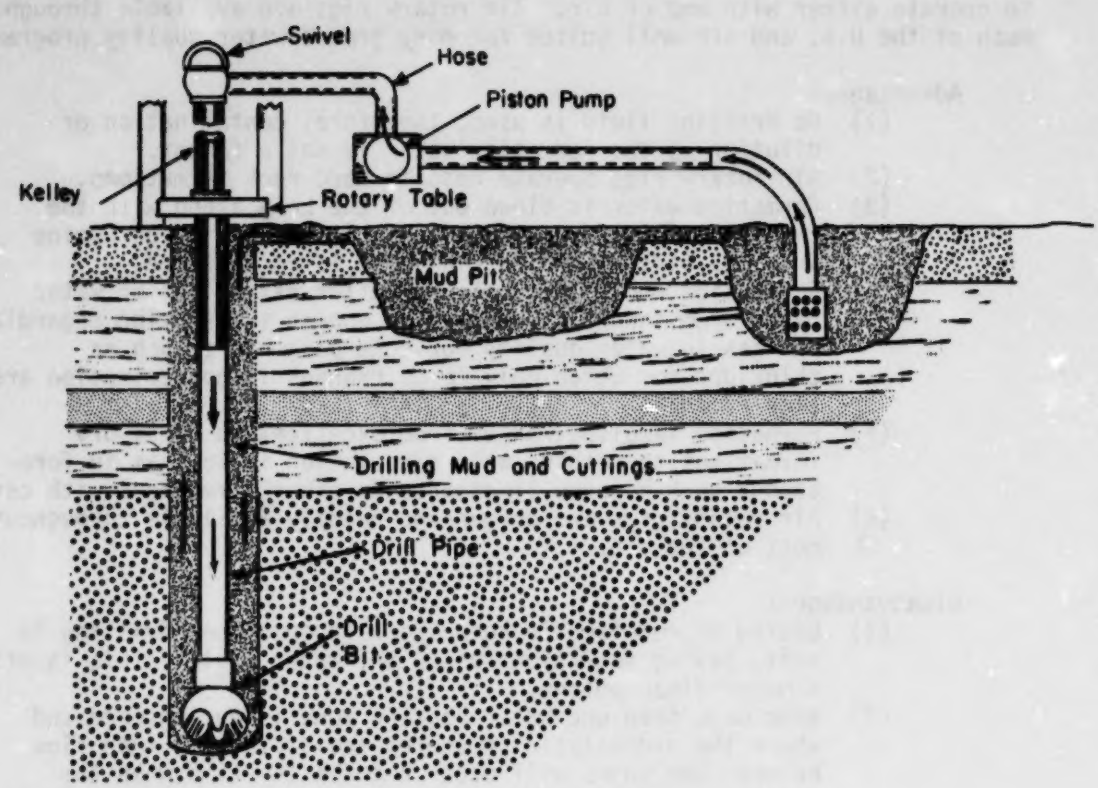
Principles of Operation: A drilling fluid is pumped down the inside of the drill pipe, and then returns to the surface through the annulus between the drill pipe and the borehole wall (Figure 8). This fluid cools the drill bit, carries the cuttings to the surface, prevents excessive fluid loss into the formation, and prevents the formation from caving. The rotating drill pipe turns the bit which cuts the formation allowing the cuttings to be flushed out.

The drilling fluid may be clear water, water mixed with bentonite or water mixed with a biodegradable organic "mud".

Mud rotary rigs are the most common rig available. Other types of drilling rigs are, however, better suited for certain geologic environments and for many water-quality sampling programs.

Advantages:
(1) Available throughout the U.S.
(2) Capable of drilling all formations, hard or soft.
(3) Capable of drilling to any depth desired for monitoring.
(4) Casing not required during drilling.
(5) Formation logging (sampling) is fairly reliable in most formations.
(6) Relatively inexpensive.

Disadvantages:
(1) Drilling fluid mixes with formation fluid and is often difficult to completely remove.
(2) Bentonite (if used to minimize fluid loss) will adsorb metals and may interfere with some other parameters, thereby making this drilling method (at least the use of bentonite drilling mud) undesirable where metals are being sampled.
(3) Organic/biodegradable additives mixed with the water to minimize fluid loss will interfere with bacterial analyses and organic-related parameters.
(4) No information on the position of the water table, and only limited information on water-producing zones is directly available during drilling. Electric logging of rotary drilled wells can substantially add to the accuracy of the driller's log and to water-related information.
(5) Circulates contaminants.


Swivel
Hose
Piston Pump
Kelley
Rotary Table
Mud Pit
Drilling Mud and Cuttings
Drill Pipe
Drill
Bit

The drilling fluid (or water) is pumped through the swivel and down through the kelley which is turned by the rotary table. The mud then flows down through the drill pipe, out through the bit and back up the hole carrying cuttings which settle out of the mud in the first section(s) of the mud pit.

Figure 8. Mud Rotary Drilling

Air Rotary

Principles of Operation: An air-rotary rig operates in the same manner as a mud-rotary rig except that air is circulated down the drill pipe and returns (bringing the cuttings) up the annulus. Some rotary rigs are equipped to operate either with mud or air. Air rotary rigs are available throughout much of the U.S. and are well suited for many ground-water quality programs.

Advantages:

(1) No drilling fluid is used, therefore, contamination or dilution of the formation water is not a factor.

(2) Air-rotary rigs operate best in hard rock formations.

(3) Formation water is blown out of the hole along with the cuttings, therefore, it is possible to readily determine when the first water-bearing zone is encountered.

(4) Collection and field analysis (after filtering) of water blown from the hole can provide enough information regarding changes in water quality for some parameters such as chlorides for which only large changes in concentration are significant.

(5) Formation sampling ranges from excellent in hard, dry formations to nothing when circulation is lost as in formations such as some limestones or other formations with cavities.

(6) Air rotary rigs are common and readily available throughout most of the U.S.

Disadvantages:

(1) Casing is required to keep the hole open when drilling in soft, caving formations below the water table. This is often a major disadvantage.

(2) When more than one water-bearing zone is encountered and where the hydrostatic pressures are different, then flow between the zones will occur between the time when the drilling is done and the hole can be properly cased and one zone grouted off.

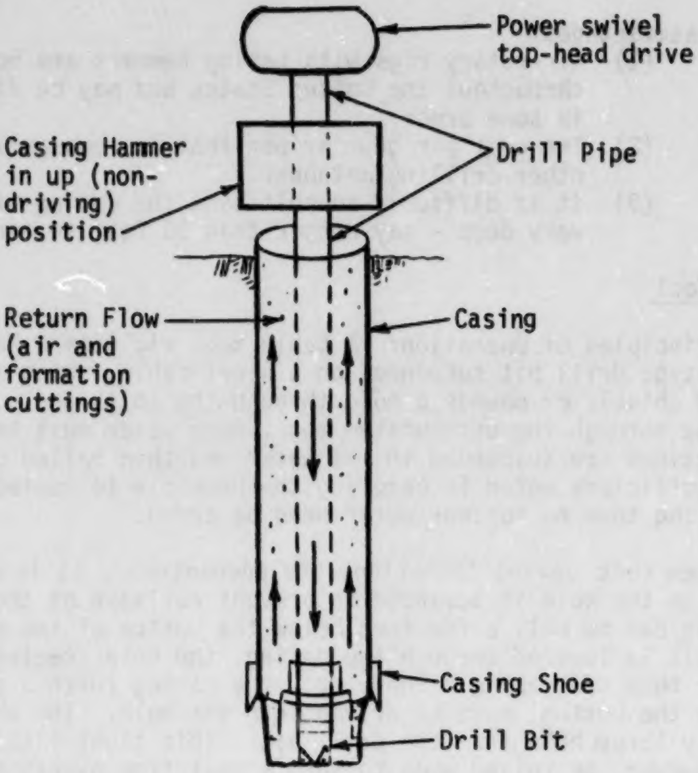
Air Drilling with Casing Hammer

Principles of Operation: A top-head drive rotary rig can be modified to accept a casing hammer. The method of drilling is the same as with air rotary except that when caving formations are encountered the casing hammer drives the casing down to prevent the hole from caving (Figure 9). The casing can be driven without withdrawing the drill pipe. This drilling method is generally excellent for constructing monitoring wells in unconsolidated formations.

Advantages:

(1) Same advantages as with standard air rotary drilling except that soft, caving formations can be drilled.

(2) The use of casing minimizes flow into the hole from upper water-bearing layers, therefore multiple layers can be penetrated and sampled for rough field determinations of some water quality parameters.


Power swivel top-head drive
Casing Hammer in up (non-driving) position
Drill Pipe
Return Flow (air and formation cuttings)
Casing
Casing Shoe
Drill Bit

An air drill with casing hammer operates like an air rotary drill except that in caving formations the casing can be driven to hold the hole open. The casing hammer is slipped down over the drill pipe and attached to the top of the casing and by a hammering motion, drives the casing. Usually the drill bit has drilled below the casing somewhat, but the casing shoe cuts a larger hole than the drill bit and therefore has to be driven.

Figure 9. Air Drill with Casing Hammer

Disadvantages:

(1) Air-rotary rigs with casing hammers are not in common use throughout the United States and may be difficult to locate in some areas.

(2) The cost per hour or per foot is substantially higher than other drilling methods.

(3) It is difficult to pull back the casing if it has been driven very deep - say deeper than 50 feet in many formations.

Cable Tool

Principles of Operation: A cable tool rig uses a heavy, solid-steel, chisel-type drill bit suspended on a steel cable, which when raised and dropped chisels or pounds a hole through the soils and rock (Figure 10). When drilling through the unsaturated zone, some water must be added to the hole. The cuttings are suspended in the water and then bailed out periodically. After sufficient water is entering the borehole to replace the water removed by bailing then no further water need be added.

When soft caving formations are encountered, it is necessary to drive casing as the hole is advanced to prevent collapse of the hole. Often the drilling can be only a few feet below the bottom of the casing. Because the drill bit is lowered through the casing, the hole created by the bit is smaller than the casing. Therefore, the casing (with a sharp, hardened casing shoe on the bottom) must be driven into the hole. The shoe in fact cuts a slightly largerhole than the drill bit. This tight-fitting drive shoe should not, however, be relied upon to form a seal from overlying water-bearing zones in water quality investigations.

Advantages:

(1) Formation samples can be excellent with a skilled driller using a sand-pump bailer.

(2) Information regarding water-bearing zones is readily available during the drilling. Even relative permeabilities and rough water quality data from different zones penetrated can be obtained by skilled operators.

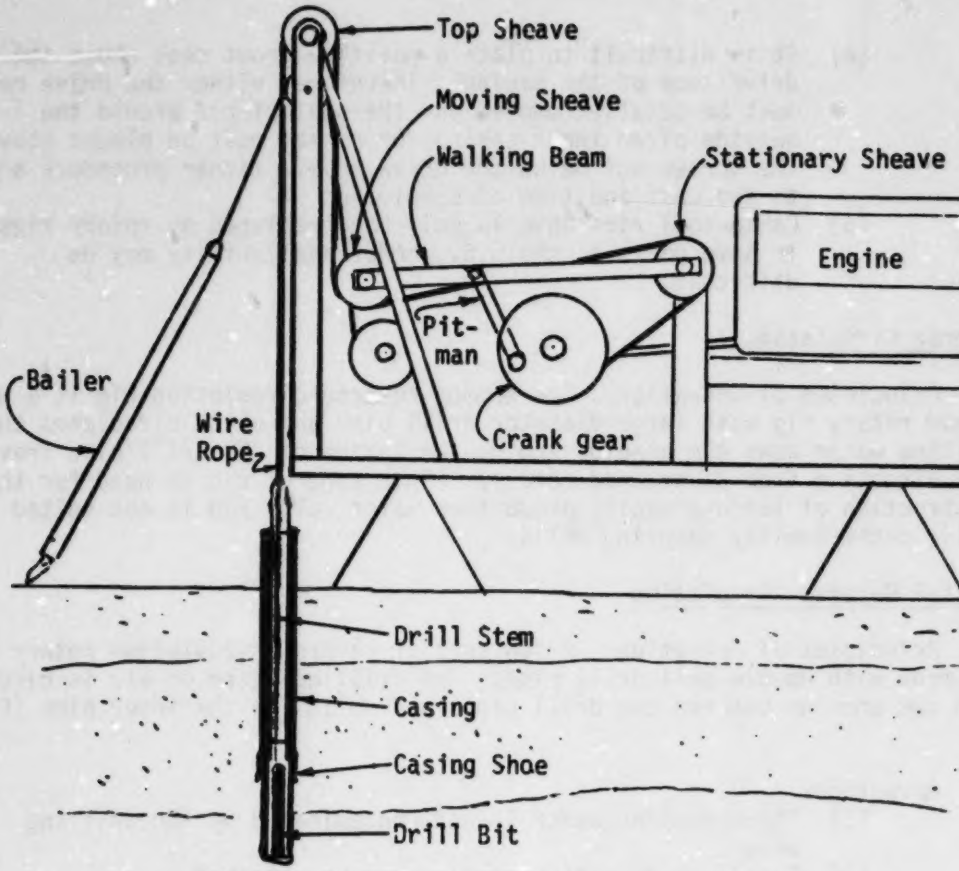
(3) The cable-tool rig can operate satisfactorily in all formations, but is best suited for caving, large gravel type formations or formations with large cavities above the water table (such as limestones).

Disadvantages:

(1) Drilling is slow compared with rotary rigs.

(2) The necessity of driving the casing along with drilling in unconsolidated formations requires that the casing be pulled back to expose selected water-bearing zones. This process complicates the well completion process and often increases costs.

(3) The relatively large diameters required (minimum of 4-inch casing) plus the cost of steel casing result in large costs compared with rotary drilling and plastic casing.


Top Sheave
Moving Sheave
Walking Beam
Stationary Sheave
Engine
Pit-
man
Bailer
Wire
Rope
Crank gear
Drill Stem
Casing
Casing Shoe
Drill Bit

The cable tool (sometimes called churn drill or percussion drill) operates as follows: Rotation of the crank gear causes the pitman to raise and lower the walking beam which is anchored at the stationary sheave end. The moving sheave end of the walking beam moves up and down causing the wire rope passing over the top sheave to alternately raise and lower the heavy drill stem and bit which drills the hole. The bailer is used to remove cuttings, and the casing is driven into the hole to prevent caving in soft formations.

Figure 10. Cable Tool Drilling

(4) It is difficult to place a positive grout seal above the drive shoe of the casing. Therefore, either the drive casing must be totally removed and the seal placed around the outside of an inner casing, or a seal must be placed above the screen but below the drive shoe. Either procedure adds to the cost and time of completion.
(5) Cable-tool rigs have largely been replaced by rotary rigs in some parts of the U.S., hence availability may be difficult.

Reverse Circulation

Principles of Operation: The common reverse-circulation rig is a water or mud rotary rig with large diameter drill pipe and which circulates the drilling water down the annulus and up the inside of the drill pipe (reverse flow direction from direct mud rotary). This type of rig is used for the construction of large-capacity production water wells and is not suited for small, water-quality sampling wells.

Special Reverse Circulation

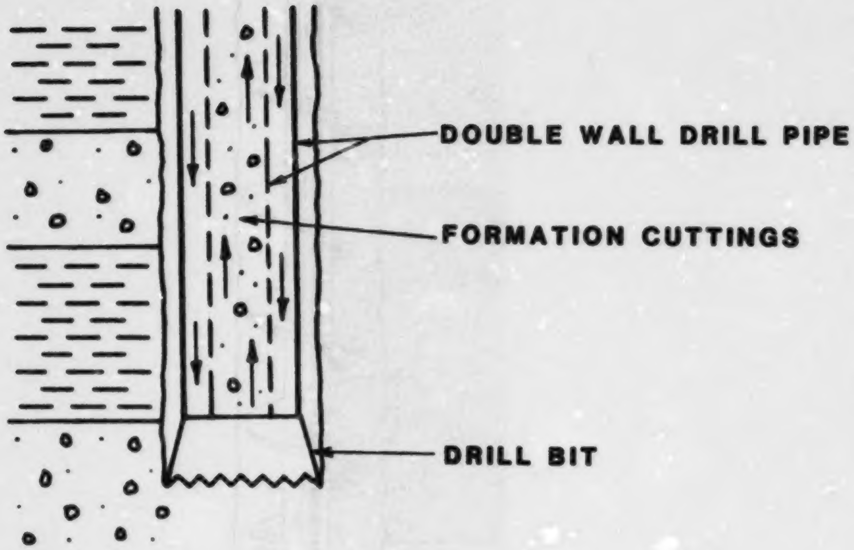
Principles of Operation: A few special reverse-circulation rotary rigs are made with double-wall drill pipe. The drilling water or air is circulated down the annulus between the drill pipes and up inside the inner pipe (Figure 11).

Advantages:
(1) The formation water is not contaminated by the drilling water.
(2) Excellent formation samples can be obtained.
(3) When drilling with air, immediate information is available regarding the water-bearing properties of formations penetrated.
(4) Caving of the hole in unconsolidated formations is not as great a problem as when drilling with the normal air rotary rig.

Disadvantages:
(1) Double-wall, reverse-circulation rigs are very rare and expensive to operate.
(2) Placing cement grout around the outside of the casing above the screen of the permanent well often is difficult - especially when the screen and casing are placed down through the inner drill pipe before the drill pipe is pulled out.

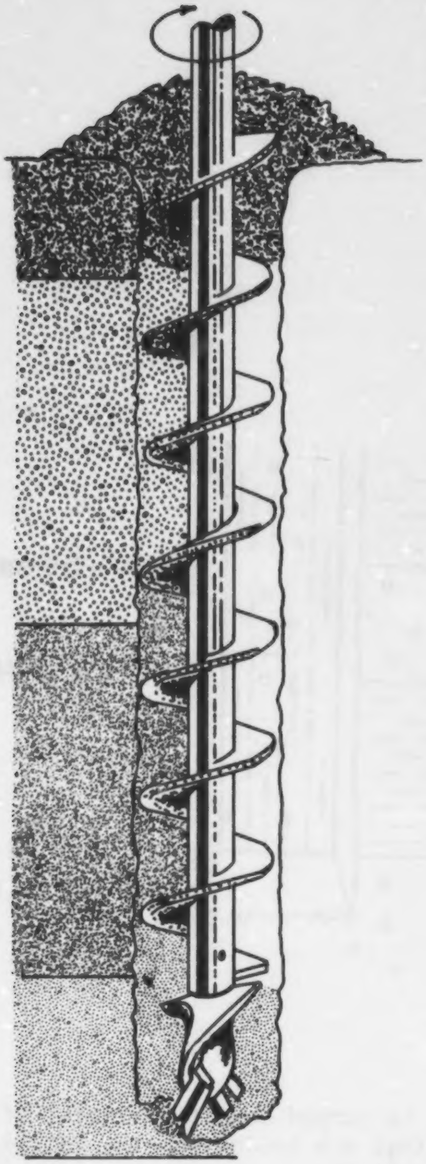
Solid-Stem Continuous-Flight Auger

Principles of Operation: Drilling is accomplished by rotating the solid stem, continuous-flight augers into the soils. As the augers are "screwed" into the soils, the cuttings are brought to the surface on the rotating flights (Figure 12). Auger bits are essentially of two types: fish tail or drag bits for use in unconsolidated materials, and claw or finger bits for


DOUBLE WALL DRILL PIPE
FORMATION CUTTINGS
DRILL BIT

Air or drilling fluid is pumped down the annulus of the double-wall drill pipe. Formation cuttings are brought up the inside of the inner pipe along with the return air or fluid.

Figure 11. Special Reverse Circulation



The continuous-flight auger bores into the soil and rotates the cuttings upward along the flights. The uppermost cuttings are discharged at the surface to make room for the space of the auger as it penetrates additional soils.

Figure 12. Continuous Flight Auger Drilling

use in more compacted, lithified or cemented soils. Once the desired depth is reached, the augers are allowed to rotate to clean out the borehole. The augers are then removed from the borehole and well screen and casing installed. This method is best applied when installing monitor wells in shallow unconsolidated formations.

Advantages:

(1) The auger drilling rigs are generally mobile, fast and inexpensive to operate in unconsolidated formations.
(2) No drilling fluid is used, therefore contamination problems are minimized.

Disadvantages:

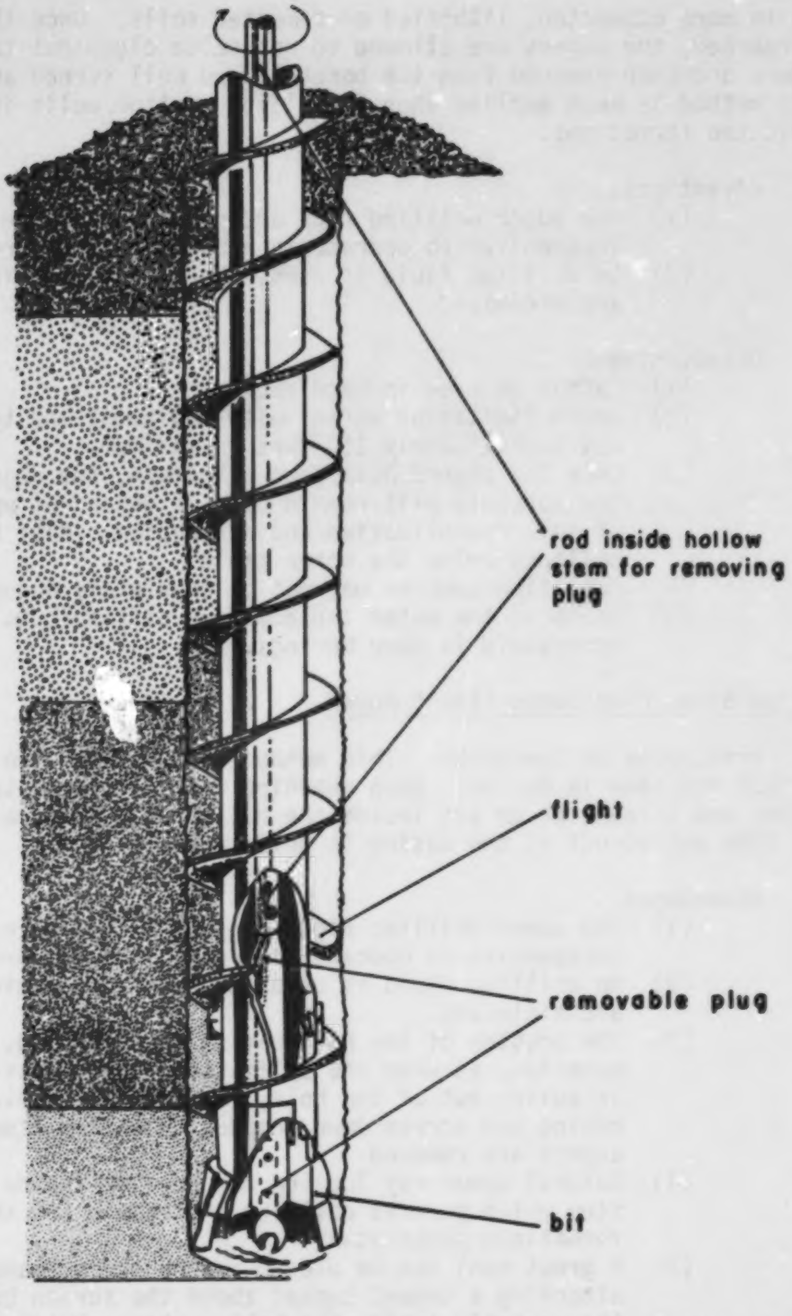
(1) Cannot be used in hard rock.
(2) Depth limitation varies with equipment and type of soils but approximately 150 feet is maximum.
(3) Once the augers have been withdrawn, the degree to which the borehole will remain open is dependent upon the degree of soil consolidation and saturation. Most boreholes will collapse below the water table.
(4) Formation samples may not be completely accurate.
(5) Depth to the water table may be difficult to determine accurately in deep borings.

Hollow-Stem, Continuous-Flight Auger

Principles of Operation: This method differs from the solid stem augers in that the stem is hollow. Upon reaching the desired depth, a small diameter casing and screen can be set inside the hollow stem (Figure 13). The augers are then pulled-out as the casing is held in place.

Advantages:

(1) The auger drilling rigs are generally mobile, fast, and inexpensive to operate in unconsolidated formations.
(2) No drilling fluid is used, therefore contamination problems are minimized.
(3) The problem of the hole caving in saturated, unconsolidated material, as when the solid-stem, continuous-flight auger is pulled out of the hole, is overcome by placing the casing and screen down inside the hollow stem before the augers are removed.
(4) Natural gamma-ray logging can be done inside the hollow stem which permits defining the nature and thickness of the formations penetrated.
(5) A grout seal can be placed around the permanent casing by attaching a cement basket above the screen before setting the assembly inside the hollow stem. Grout is placed in the annulus between the casing and hollow stem and the augers are pulled out. Grout is continuously injected or placed until all augers are removed.


rod inside hollow stem for removing plug
flight
removable plug
bit

The hollow-stem, continuous-flight auger bores into soft soils carrying the cuttings upward along the flights. When the desired depth is reached, the plug is removed from the bit and withdrawn from inside the hollow stem. A well point (1½-in. or 2-in.) can then be inserted to the bottom of the hollow stem and the auger pulled out leaving the small-diameter monitoring well in place.

Figure 13. Hollow Stem Auger Drilling

Disadvantages:

(1) Cannot be used in hard rock.
(2) Depth limitation varies with equipment and type of soils but approximately 150 feet is practical.
(3) Formation samples may not be completely accurate.
(4) Depth to the water table may be difficult to determine accurately in deep borings.

Keck Screened, Hollow Stem, Continuous Flight Auger(14)

Principles of Operation: This method operates the same as the hollow-stem augers except that the lead section incorporates a well screen (Figure 14).

Advantages:

(1) The auger drilling rigs are generally mobile, fast and inexpensive to operate in unconsolidated formations.
(2) No drilling fluid is used, therefore contamination problems are minimized.
(3) The problem of the hole caving in saturated, unconsolidated material, as when the solid-stem, continuous-flight auger is pulled out of the hole, is overcome by placing the casing and screen down inside the hollow stem before the augers are removed.
(4) Natural gamma-ray logging can be done inside the hollow stem which permits defining the nature and thickness of the formations penetrated.
(5) A grout seal can be placed around the permanent casing by attaching a cement basket above the screen before setting the assembly inside the hollow stem. Grout is placed in the annulus between the casing and hollow stem and the augers are pulled out. Grout is continuously injected or placed until all augers are removed.
(6) Depth to water table can be accurately determined.
(7) Water samples can be collected at any desired depth below the water table during the drilling operation without removing the augers or setting a screen and casing.

Disadvantages:

(1) Cannot be used in hard rock.
(2) Depth limitation varies with equipment and type of soils but approximately 150 feet is practical.
(3) Formation samples may not be completely accurate.

Bucket Auger

Principles of Operation: The bucket auger consists of a relatively large (8-inch minimum diameter by 2 feet long) bucket with a cutting edge on the bottom which is slowly rotated by a square, telescoping kelley or drill stem. When the bucket fills with cuttings, it is brought to the surface and emptied. This method is good for constructing shallow wells just into the water table in unconsolidated formations.

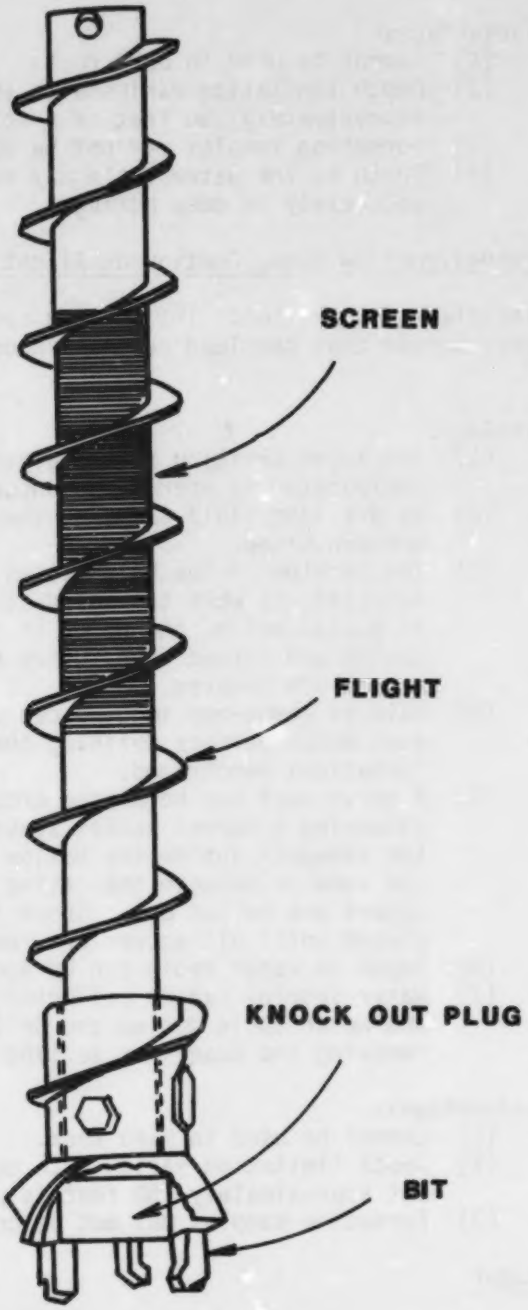

SCREEN
FLIGHT
KNOCK OUT PLUG
BIT

Figure 14. Keck Screened, Hollow Stem, Continuous Flight Auger

Advantages:

(1) No drilling water is required when either drilling above the saturated zone, or below the saturated zone in non-caving formations.
(2) After the hole has been drilled, the setting of casing with screen and grouting the outside of the casing to form a seal is relatively easy.
(3) Formation sampling is excellent.

Disadvantages:

(1) The hole diameter is large, hence the annular space is large when small diameter casing is used. This requires careful grouting and backfilling to insure water sample integrity.
(2) In caving formations below the water table it is necessary to continuously add water to prevent caving.
(3) Use of the bucket auger is restricted to soft formations and depths less than about 50 feet.
(4) These rigs are not widely available.

Jetting

Principles of Operation: Jetting consists of pumping water or drilling mud down through a small diameter (1½ to 2-inch) standard pipe. The pipe may be fitted with a chisel bit or a special jetting screen. Formation materials dislodged by the bit and jetting action of the water are brought to the surface through the annulus around the pipe. As the pipe is jetted deeper, additional lengths of pipe may be added at the surface.

This method is acceptable in very soft formations, for shallow sampling, and when introduction of drilling water to the formation is not a consideration.

Advantages:

(1) Jetting is fast and very inexpensive.
(2) Because of the small amount of equipment required, jetting can be accomplished in locations where it would be very difficult to get a normal drilling rig. For example, it would be possible to jet down a well point in the center of a lagoon at a fraction of the cost of using a drill rig.
(3) Jetting numerous well points just into a shallow water table is an inexpensive method for determining the water table contours, hence flow direction.

Disadvantages:

(1) A large amount of foreign water or drilling mud is introduced above and into the formation to be sampled.
(2) It is not possible to place a grout seal above the screen to assure depth-discrete sampling.
(3) The diameter of the casing is usually limited to two inches therefore, obtaining samples must be either by suction lift, air lift, bailer, or other methods applicable to small diameter casings.
(4) Jetting is only possible in very soft formations, and the depth limitation is shallow - say 30 feet without special equipment.
(5) Large quantities of water are often needed.

Use of Bore-Hole Geophysics

The use of geophysics can greatly enhance the amount of information gained from a borehole (Figure 15). Each geophysical logging method is designed to operate in specific borehole conditions, involves lowering a sensing device into the borehole and can be interpreted to determine lithology, geometry, resistivity, bulk density, porosity, permeability, moisture content and to define the source, movement, chemical and physical characteristics of ground water (5).

1. Spontaneous-Potential Log: These logs are records of the natural potentials developed between the borehole fluid and the surrounding rock/soil materials. The SP log is mainly used for geologic correlation, determining bed thickness and separating non-porous from porous rocks in shale-sandstone and shale-carbonate sequences. It can be run only in open, uncased and fluid filled boreholes.

2. Normal Resistivity Logs: Normal logs measure the apparent resistivity of a volume of rock/soil surrounding. The short normals give good vertical detail and records the apparent resistivity of the mud invaded zone. The long normals record the apparent resistivity beyond the invaded zone. The radius of investigation is generally equal to the distance between the borehole current and measuring electrodes. These logs can be run only in open, uncased and fluid filled boreholes.

3. Natural-Gamma Logs: Natural-gamma logs or gamma-ray logs are records of the amount of natural-gamma radiation emitted by rocks/soils. The main use of this logging method is for the identification of lithology and stratigraphic correlation. These logs can be run in open or cased, fluid or air filled boreholes. The radius of investigation extends to about 6-12 inches of the borehole wall.

4. Gamma-gamma Logs: These logs record the intensity of gamma radiation from a source in the probe after it is backscattered and attenuated within the borehole and surrounding rocks/soil. The main uses of gamma-gamma logs are for identification of lithology and measurement of bulk density and porosity of rocks/soils. They are also used for

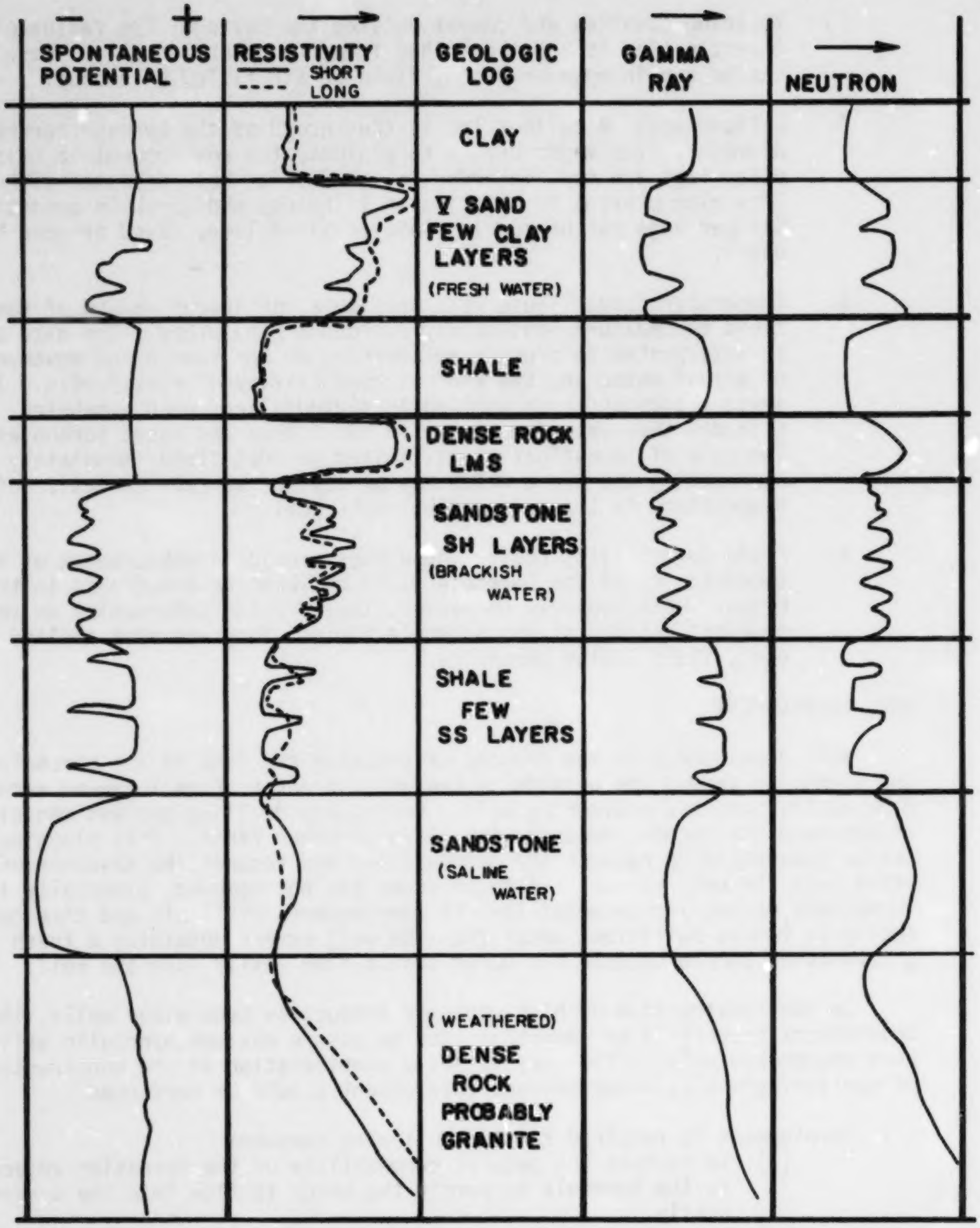

− +
SPONTANEOUS POTENTIAL
RESISTIVITY
SHORT
LONG
GEOLOGIC LOG
GAMMA RAY
NEUTRON
CLAY
V SAND FEW CLAY LAYERS
(FRESH WATER)
SHALE
DENSE ROCK LMS
SANDSTONE SH LAYERS
(BRACKISH WATER)
SHALE FEW SS LAYERS
SANDSTONE
(SALINE WATER)
(WEATHERED)
DENSE ROCK PROBABLY GRANITE

Figure 15. Comparison of Electric and
Radioactive Bore Hole Logs

locating cavaties and cement outside the casing. The radius of investigation is about 6 inches from the borehole wall. These logs can be run in open or cased, fluid or air filled boreholes.

5. Caliper Log: A caliper log is the record of the average borehole diameter. Its major use is to evaluate the environment in which other logs are made in order to correct for hole-diameter effects. They also provide information on lithology and borehole conditions. Caliper logs can be run in fluid or air filled, cased or open boreholes.

6. Temperature Log: These logs provide a continuous record of the fluid temperature immediately surrounding the probe. The data can be interpreted to provide information on the source and movement of ground water and the thermal conductivity of rocks/soils. Temperature logs are best applied in fluid filled, open boreholes although they can also be run in air filled and cased boreholes. The zone of investigation is limited to that fluid immediately surrounding the probe which may or may not be representative of the temperature in the surrounding rocks/soils.

7. Fluid-Conductivity Logs: These logs provide a measurement of the conductivity of the borehole fluid between the electrodes in the probe. When properly corrected, they provide information on the chemical quality of the borehole fluid. They are best applied in open, fluid filled boreholes.

WELL DEVELOPMENT

Well development is the process of cleaning the face of the borehole and the formation around the outside of the well screen to permit ground water to flow easily into the monitoring well. During any drilling process the side of the borehole becomes smeared with clays or other fines. This plugging action substantially reduces the permeability and retards the movement of water into the well screen. If these fines are not removed, especially in formations having low permeability, it then becomes difficult and time consuming to remove sufficient water from the well before obtaining a fresh ground-water sample because the water cannot flow easily into the well.

In the construction of high-capacity production type water wells, the development process is an important step to assure maximum hydraulic efficiency. Even though hydraulic efficiency is not a consideration in the construction of monitoring wells, nevertheless, development should be performed.

Development is required for the following reasons:

(1) To restore the natural permeability of the formation adjacent to the borehole to permit the water to flow into the screen easily.
(2) To remove the clay, silt and other fines from the formation so that during subsequent sampling the water will not be turbid or contain suspended matter which can easily interfere with chemical analysis.

The development process is best accomplished for monitoring wells by causing the natural formation water inside the well screen to move vigorously in and out through the screen in order to agitate the clay and silt, and move these fines into the screen. The use of water other than the natural formation water is not recommended.

Methods suitable for the development of monitoring wells are as follows:

(1) Surge block.

A surge block is a round plunger with pliable edges such as belting that will not catch on the well screen. Moving the surge block forcefully up and down inside the well screen causes the water to surge in and out through the screen accomplishing the desired cleaning action.

Surge blocks are commonly used with cable-tool drilling rigs, but are not easily used by other types of drilling rigs.

(2) Air lift.

Compressed air pumped down a pipe inside the well casing can be used to blow water out of the monitoring well. If air is applied to the well intermittently and for short periods then the water is only raised inside the casing rather than blown out and will fall back down the casing causing the desired back washing action. Finally, blowing the water out will remove the fines brought into the screen by the agitating action.

Considerable care must be exercised to avoid injecting air into the well screen. Such air can become trapped in the formation outside the well screen and alter subsequent chemical analyses of water samples. For this reason, the bottom of the air pipe should never be placed down inside the screen.

Another restriction on the use of air is the submergence factor. Submergence is the feet of water above the bottom of the air pipe while pumping (blowing water out) divided by the total length of the air pipe. Submergence should be on the order of at least 20 percent, which may be difficult to achieve with many shallow monitoring wells.

(3) Bailer.

A bailer sufficiently heavy that it will sink rapidly through the water can be raised and lowered through the well screen. The resulting agitating action of the water is similar to that caused by a surge block. The bailer, however, has the added advantage of removing the fines each time it is brought to the surface and dumped. Bailers can be custom-made for small diameter wells, and can be hand-operated in shallow wells.

(4) Surging by pumping.

Starting and stopping a pump so that the water is alternately pulled into the well through the screen and backflushed through the screen is an effective development method. Periodically pumping to waste will remove the fines from the well and permit checking the progress to assure that development is complete.

In conclusion, development of monitoring wells, although often overlooked, is an important function of the well construction in order to facilitate future sampling and to obtain samples free of turbidity.

MULTIPLE-COMPLETION SAMPLING WELLS

Most ground water pollution is relatively shallow and affects the first and sometimes the second permeable layers. Conventional wells completed in specific permeable layers are constructed so that each well is depth-specific.

Occasionally, it is desired to sample numerous permeable layers at considerable depth, perhaps at a few hundred feet. If, for example, it is desired to define the bottom of the pollution plume and then to periodically sample the lower-most contaminated layer, a cemented and gun-perforated well can be constructed. Or, if permanent monitoring in several deep layers is required such as for underground injection wells, then the permanent type multiple-completion well should be considered.

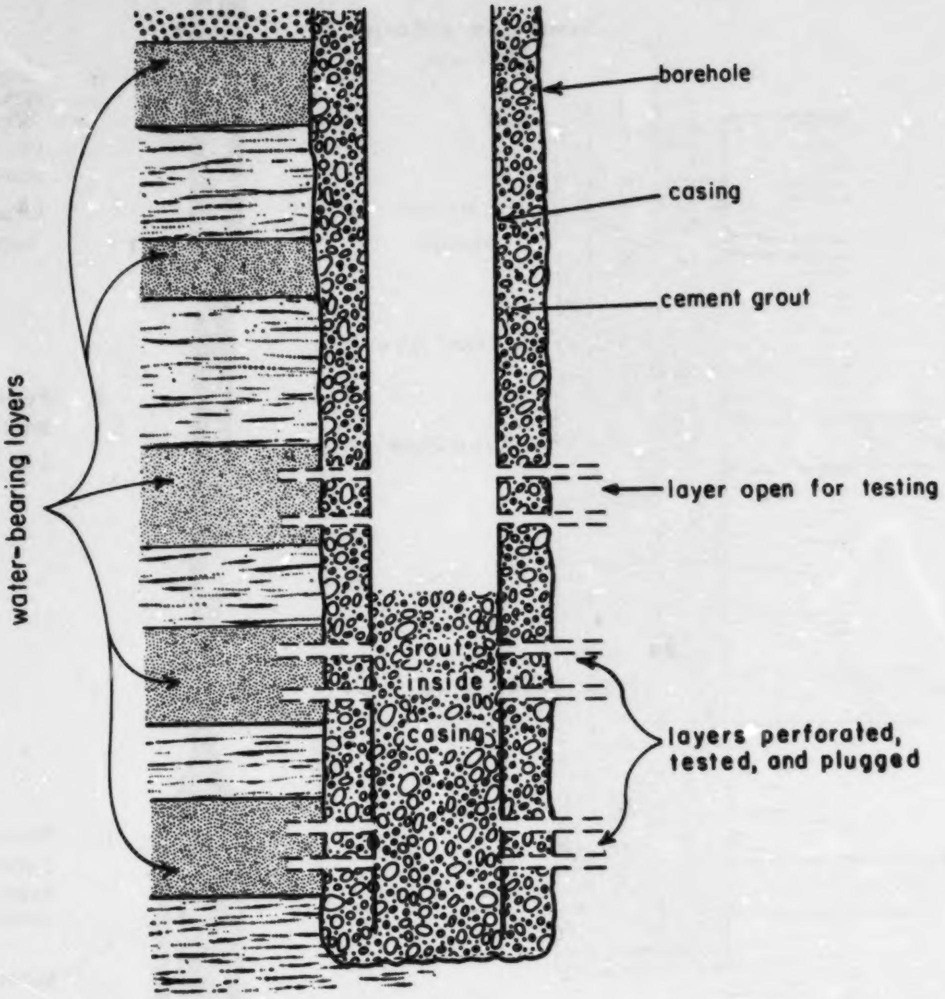
Figure 16 illustrates the construction of a gun-perforated well. This type of well is commonly drilled and logged to define the depth of all the permeable layers. Then casing is installed with centralizers and cement grout is placed in the annulus from the bottom up to surround the casing. The grout prevents intercommunication between permeable layers along the outside of the casing.

The casing is then perforated opposite the bottom-most permeable layer. Water from this layer is pumped out, sampled, and analyzed and the static level is measured. If no contaminants are present, then cement grout is pumped through a tremie pipe to fill the inside of the casing up past the perforations thereby permanently sealing that zone. The second zone from the bottom may then be perforated, sampled, and sealed if no contaminants are found. This procedure may be repeated until contaminants are observed at which time the well may be left to periodically monitor that layer, or plugged and upper layers sampled.

Care must be exercised to assure that sufficient water is pumped from the layer being sampled and that the sample is representative of the formation water before that layer is plugged. This approach is not recommended when the pollutants are reactive with cement.

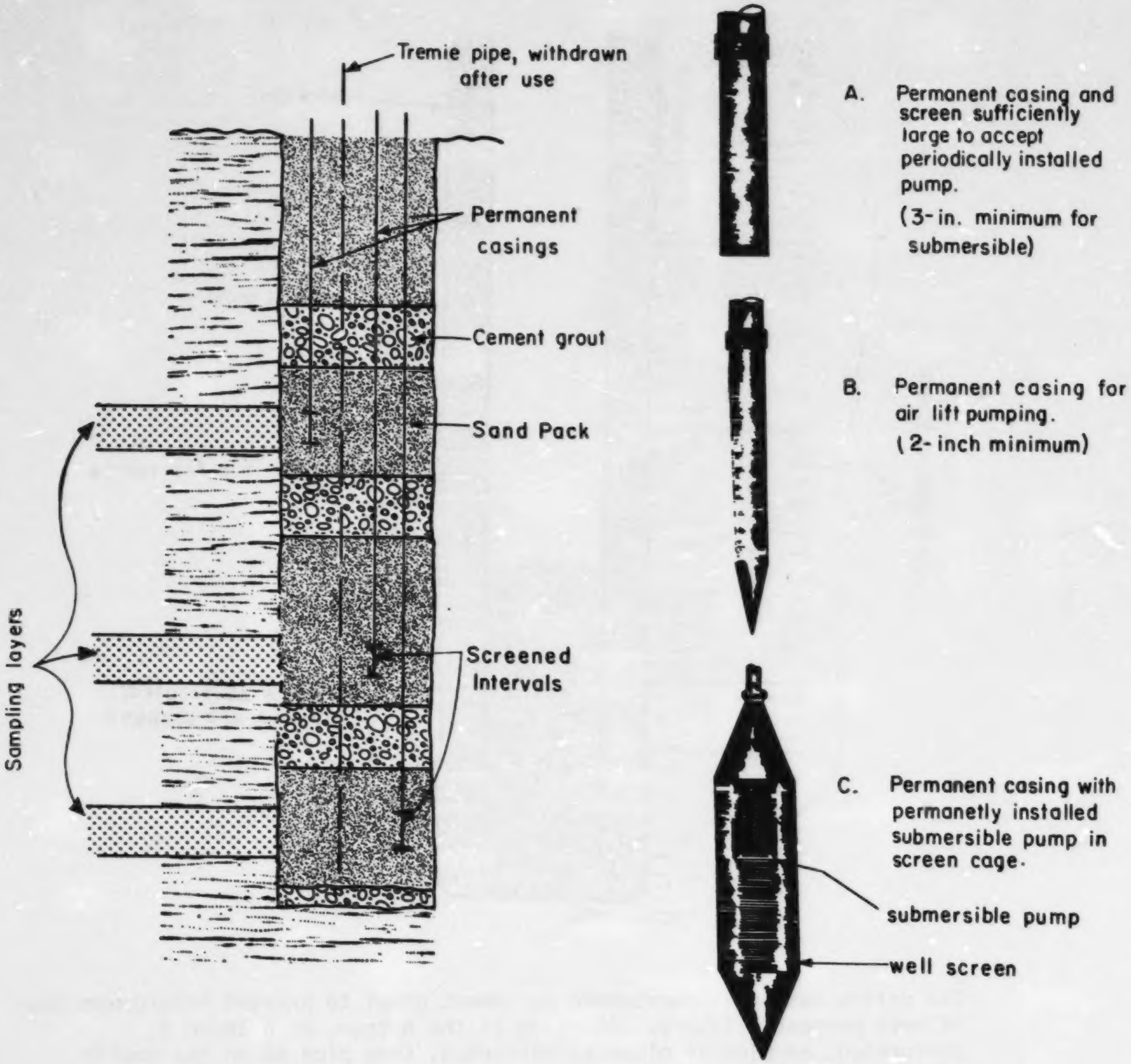
Figure 17 depicts another alternative for constructing a multiple-completion monitoring well. This approach provides for periodic sampling and permanent monitoring of each permeable layer screened rather than one-time sampling as shown in Figure 16. However, because of construction difficulties it is rarely practical to monitor at more than three depths in a well. The approach shown in Figure 16, on the other hand, permits sampling as many layers as desired, but all layers cannot be permanently monitored.

The construction of a multiple-completion monitoring well as shown in Figure 17 is difficult from the standpoint of lowering the various components in the hole simultaneously. The drilling contractor must plan and execute


borehole
casing
cement grout
water-bearing layers
layer open for testing
Grout inside casing
layers perforated, tested, and plugged

The entire casing is surrounded by cement grout to prevent interconnection between permeable layers. Starting at the bottom, each layer is perforated, sampled as often as warranted, then plugged on the inside of the casing before the next layer is perforated. This procedure permits vertical delineation of the contaminant plume in deep aquifer systems at minimum cost.

Figure 16. Multiple Completion Well, for One-Time Sampling


Tremie pipe, withdrawn after use
Permanent casings
Cement grout
Sand Pack
Screened Intervals
Sampling layers
A. Permanent casing and screen sufficiently large to accept periodically installed pump.
(3-in. minimum for submersible)
B. Permanent casing for air lift pumping.
(2-inch minimum)
C. Permanent casing with permanetly installed submersible pump in screen cage.
submersible pump
well screen

A multiple completion sampling well may be completed with pumping arrangements of A, B, or C. The sand pack material and cement grout are placed from the bottom up through the tremie pipe as the pipe is pulled out.

Figure 17. Multiple Completion Well, for Periodic Sampling

this work carefully to be successful. The tremie pipe, commonly a 2-inch pipe, is lowered into the hole along with the other pipes. Sand is pumped through the tremie pipe to place the sand pack at the desired depths, and cement grout is also pumped through the tremie to place the grout seals. A wash plug and clear water can be pumped through to clean the grout out of the pipe before the next layer of sand is placed. Or, in some cases, it may be more feasible to use two tremie pipes, one for sand and one for cement grout. In either case careful measurements are required to place the sand and grout from the bottom up as the tremie pipe is withdrawn.

After the well is completed, each screened layer should be pumped thoroughly to remove the effects of foreign water in the formation due to drilling, flushing, and placement of sand grout.

Several optional methods for constructing multiple-completion wells are available. Option "A", Figure 17, utilizes two or three 3-inch or larger casings from each screen depth all the way to ground surface. In addition the temporary tremie pipe must be installed thereby requiring a hole diameter of at least 11 to 12 inches. This option has the advantage of using one pump, which is installed as required in each casing.

Option "B", Figure 17, is the least expensive. An 8-inch hole is probably sufficient diameter for the installation of three permanent 2-inch casings plus the tremie pipe. Conceivably it may be feasible to install more than three permanent casings in a larger diameter hole, however, the difficulties in handling the materials during installation become greater. The disadvantage of the 2-inch casings is the limitation on pumping. If the layers to be sampled are highly permeable then the time required to remove invaded water from the formations becomes excessive due to the pumping limitation imposed by the small casing. Also with 2-inch casings, specialized pumping systems are required which may not be desirable considering either the aquifer characteristics or the nature of the pollutants.

Option "C", Figure 17 utilizes a permanently-installed submersible pump in a well-screen cage set at each layer to be sampled. Each pump discharges through a 2-inch pipe to the surface. Foot valves are removed from the pumps to permit static water levels to be measured. This approach has the advantage of using submersible pumps for sampling highly permeable layers with deep static levels, yet keeping the diameter of the hole smaller than that required for Option "A". The maximum installed diameter would be the OD of the screen (4-inches), plus two 2-inch discharge pipes, plus the 2-inch tremie pipe; therefore, installation into a 9 or 10 inch hole should be feasible. Installation of this system is complicated, however, by the electric wiring that must be installed to operate each pump. A disadvantage is the questionable life-expectancy of the pumps; they cannot be replaced if they fail.

With any type of multiple completion well in which more than one discrete depth can be sampled at any one time there is always the question of hydraulic intercommunication between layers via the well. A possible test to evaluate this potential is to measure the static levels in each casing, pump one of the monitoring wells, and if the water levels in the other monitoring wells do not draw down, then intercommunication is probably not a factor.

Because of the intercommunication potential and because of the difficulties in construction, the use of multiple completion wells should be avoided except where this approach is significantly more cost-effective than individual wells.

SECTION 6

COLLECTION OF GROUND WATER SAMPLES

GENERAL REQUIREMENTS

The importance of proper sampling of wells cannot be overemphasized. Even though the well being sampled may be correctly located and constructed, special precautions must be taken to ensure that the sample taken from that well is representative of the ground water at that location and that the sample is neither altered nor contaminated by the sampling and handling procedure.

To obtain a representative sample of the ground water it must be understood that the composition of the water within the well casing and in close proximity to the well is probably not representative of the overall ground water quality at that sampling site. This is due to the possible presence of drilling contaminants near the well and because important environmental conditions such as the oxidation-reduction potential may differ drastically near the well from the conditions in the surrounding water bearing materials. For these reasons it is highly desirable that a well be pumped or bailed until the well is thoroughly flushed of standing water and contains fresh water from the aquifer. The recommended length of time required to pump or bail a well before sampling is dependent on many factors including the characteristics of the well, the hydrogeological nature of the aquifer, the type of sampling equipment being used, and the parameters being sampled. The time required may range from the time needed to pump or bail one bore volume to the time needed to pump several bore volumes. A common procedure is to pump or bail the well until a minimum of four (4) to ten (10) bore-volumes have been removed.

Other factors which will influence the time required to flush out a well before sampling include the pumping rate and the placement of the pumping equipment within the column of water in the well bore. Care should be taken to ensure that all of the water within the well bore is exchanged with fresh water. For example, recent studies have shown that if a pump is lowered immediately to the bottom of a well before pumping, it may take some time for the column of water above it to be exchanged if the transmissivity of the aquifer is high and the well screen is at the bottom of the casing (6) (7). In such cases the pump will be pumping primarily water from the aquifer. Gibb notes that removing all water from the well bore is only possible if the well is pumped dry and suggests two alternative approaches: (a) monitor the water level in the well while pumping. When the water level has "stabilized" most if not all of the water being pumped is coming from the aquifer.

(b) Monitor the temperature and pH of the water while pumping. When these two parameters "stabilize" it is probable that little or no water from casing storage is being pumped (7).

Specific details regarding the type of sampling equipment required for specific chemical and biological parameters are discussed in detail in the following sections. The sampling equipment used must not alter or contaminate the sample. For example, if the sample is to be analyzed for trace organic chemicals, special care must be taken since such sampling equipment as conventional oil-lubricated pumps, tygon, and rubber tubing can be serious sources of contamination. However, such equipment is usually satisfactory for sampling for many other parameters. Sterile sampling gear may be essential for biological monitoring. In each case the selection of sampling equipment will be dependent on the nature of the parameters of interest.

Interest in ground-water quality monitoring has recently been increasing at an exponential rate and significant advances in the sampling state-of-the-art will undoubtedly follow. For this reason and because the authors may be unaware of some very effective alternatives, identification of equipment by specific manufacturers has been avoided in most cases.

WITHDRAWING SAMPLES

This section is primarily concerned with the collection of water samples from the saturated zone of the subsurface. The type of system used is a function of the type and size of well construction, pumping level, type of pollutant, analytical procedures and presence or absence of permanent pumping fixtures. Ideally, sample withdrawal mechanisms should be completely inert; economical to manufacture; easily cleaned, sterilized and reused; able to operate at remote sites in the absence of external power sources; and capable of delivering continuous but variable flow rates for well flushing and sample collection.

Most water supply wells contain semi-permanently mounted pumps which limit the options available for ground water sampling. Existing in-place pumps may be line shaft turbines, commonly used for high capacity wells, submersible pumps very commonly used in domestic wells for high-head, low capacity applications, and more recently for municipal and industrial uses, and jet pumps commonly used for shallow, low capacity domestic water supplies. The advantage of in-place pumps are that water samples are readily available and non-representative stagnant water in the well bore is generally not a problem. The disadvantages are that excessive pumping can dilute or increase the contaminant concentrations from what is representative of the sampling point, that water supply wells may produce water from more than one aquifer, and contamination and/or adsorption may be a problem when sampling for organics.

The advantage to collecting water samples from monitoring wells without in-place pumps is in the flexibility of selecting equipment and procedures. The principal disadvantage is the possibility of a non-representative sample either through collecting stagnant water that is in the well bore or introducing contamination from the surface by the sampling equipment or procedures. Some commonly used systems are described below:

Bailers

One of the oldest and simplest methods of sampling water wells is the use of bailers. A bailer may be in the form of a weighted bottle or capped length of pipe on a rope or some modification thereof which is lowered and raised generally by hand. Two examples are represented in Figures 18 and 19. The modified Kemmerer Sampler is often used for sampling surface waters as well as ground waters. The Teflon bailer was developed specifically for collecting ground water samples for volatile organic analysis.

Advantages:
(1) It can be constructed from a wide variety of materials compatible with the parameter of interest.
(2) Economical and convenient enough that a separate bailer may be dedicated to each well to minimize cross contamination.
(3) No external power source required.
(4) Low surface to volume ratio reduces outgassing of volatile organics

Disadvantages:
(1) Sometimes impractical to evacuate stagnant water in a well bore with a bailer.
(2) Transfer of water sample from bailer to sample bottle can result in aeration.
(3) Cross-contamination can be a problem if equipment is not adequately cleaned after each use.

Suction Lift Pumps

There are a variety of pumps available that can be used when the water table is within suction lift, i.e., less than about 20 feet. Centrifugal pumps are the most commonly available, are highly portable and have pumping rates from 5 to 40 gpm. Most of these require a foot-value on the end of the suction pipe to aid in maintaining a prime.

Peristaltic pumps are generally low-volume suction pumps suitable for sampling shallow, small diameter wells. Pumping rates are generally low but can be readily controlled within desirable limits. One significant limitation is the low pumping rates used initially to flush out the well bore. Another limitation is that electrical power is required. Hand operated diaphragm pumps are available that can be operated over a wide range of pumping rates which facilitates rapid evacuation of a well bore initially and lower controlled pumping rates for subsequent sampling. One major advantage is portability.

Advantages:
(1) Generally, suction lift pumps are readily available, relatively portable, and inexpensive.

Disadvantages:
(1) Sampling is limited to ground water situations where water levels are less than about 20 feet.

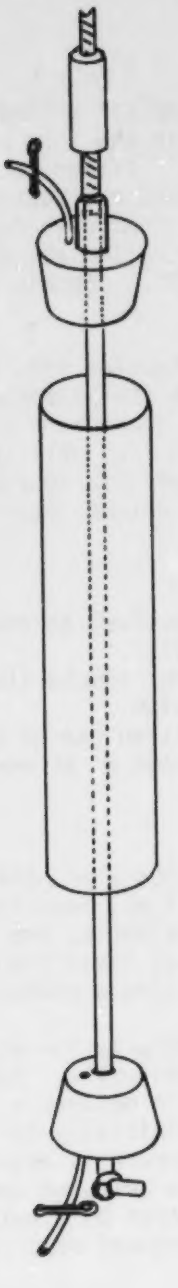


Figure 18. Modified Kemmerer Sampler (2)

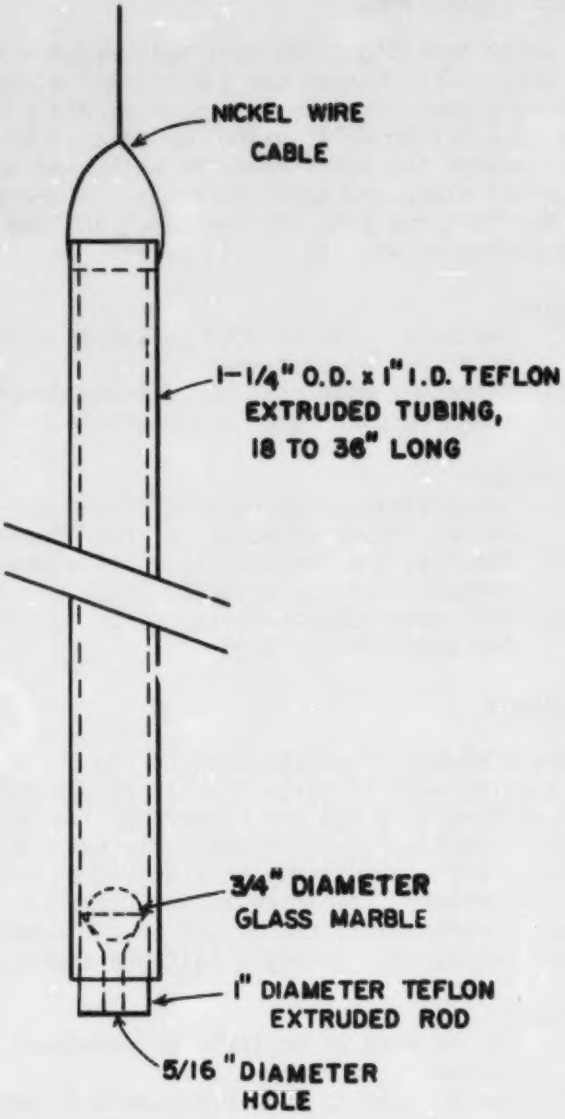

NICKEL WIRE CABLE
1-1/4" O.D. x 1" I.D. TEFLON EXTRUDED TUBING, 18 TO 36" LONG
3/4" DIAMETER GLASS MARBLE
1" DIAMETER TEFLON EXTRUDED ROD
5/16" DIAMETER HOLE

Figure 19. Teflon Bailer (14)

(2) May result in degassing and loss of volatile compounds.

Portable Submersible Pumps

Ground water investigations routinely require the collection of samples from depths which often exceed the limitations of conventional sampling equipment. One such system consists of a submersible pump which can be lowered or raised in an observation well, using 300 feet of hose that supports the weight of the pump, conveys the water from the well, and houses the electrical cable and an electrical winch and spool assembly. A portable generator provides electricity for both the pump and the winch and the entire assembly can be mounted in a pickup or van (8).

Advantages:
(1) Portable. Can be used to sample several monitoring wells in a brief period of time.
(2) Dependent upon size of pump and pumping depths, relatively large pumping rates are possible.

Disadvantages:
(1) Submersible pumps currently available require a minimum well casing inside diameter of three inches.
(2) Requires the services of a relatively large service-type vehicle - either a van or truck.
(3) With conventional construction materials, it is not suitable for sampling for organics.

Air-Lift Samplers

There are a number of adaptations to the basic method of applying air pressure to a water well to force a water sample out the discharge tube. A high-pressure hand pump and any reasonably flexible tubing can be used as a highly portable sampling unit. A small air compressor and somewhat more elaborate piping arrangements may be required at greater depths as shown in Figure 20. The primary limitation to this sampler is the potential alteration of water quality parameters, the amount of air pressure that can be safely applied to the tubing and finding a suitable source of compressed air.

Advantages:
(1) Can be used as portable or permanently installed sampling system.
(2) Can be used to both pre-pump and sample.

Disadvantages:
(1) Not suitable for pH sensitive parameters such as metals.
(2) If air or oxygen is used, oxidation is a problem.
(3) Gas stripping of volatile compounds may occur.

Nitrogen Powered, Continuous Delivery, Glass-Teflon

With the interest in sampling ground water for trace organic pollutants has come the need for a noncontaminating, nonadsorbing pump for collecting

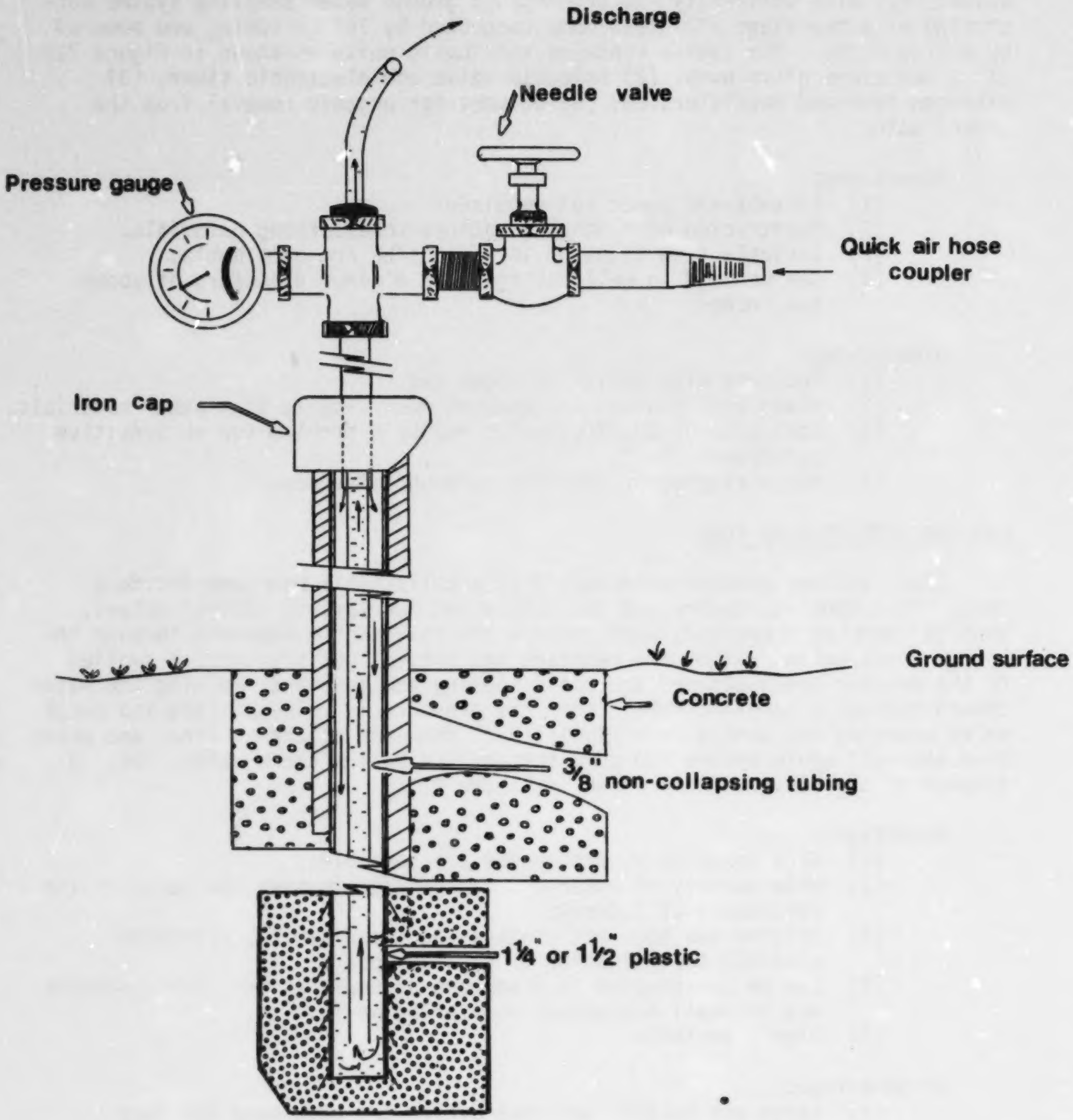

Discharge
Needle valve
Pressure gauge
Quick air hose coupler
Iron cap
Ground surface
Concrete
3/8" non-collapsing tubing
1¼" or 1½" plastic

Figure 20. Air-Lift Sampler (2)

samples below the suction lift. Based on an initial design by Stanford University, Rice University has developed a ground water sampling system consisting of a two stage all-glass pump connected by Teflon tubing and powered by nitrogen gas. The system contains four basic units as shown in Figure 21: (1) a two-stage glass pump, (2) solenoid valve and electronic timer, (3) nitrogen tank and regulator, and (4) columns for organic removal from the ground water.

Advantages:
(1) Portable-ac power not required.
(2) Constructed of noncontaminating, nonadsorbing materials.
(3) Variable flow rates up to 45 gals/hr are obtainable.
(4) Can be used in well casings with minimum diameters of about two inches.

Disadvantages:
(1) Requires high purity nitrogen gas.
(2) Glass construction is somewhat more fragile than other materials.
(3) Stripping of CO_2 from water may be a problem for pH sensitive parameters.
(4) Gas stripping of volatile compounds may occur.

Gas-Operated Squeeze Pump

These systems consist principally of a collapsible membrane inside a long, rigid housing, compressed gas supply and appropriate control valves. When the pump is submerged, water enters the collapsible membrane through the bottom check valve. After the membrane has filled, gas pressure is applied to the annular space between the rigid housing and membrane, forcing the water upward through a sampling tube. When the pressure is released, the top check valve prevents the sample from flowing back down the discharge line, and water from the well again enters the pump through the bottom check valve (10). A diagram of the basic unit is shown in Figure 22.

Advantages:
(1) Wide range in pumping rates are possible.
(2) Wide variety of materials can be used to meet the needs of the parameters of interest.
(3) Driving gas does not contact the water sample, eliminate possible contamination or gas stripping.
(4) Can be constructed in diameters as small as one inch - permits use of small economical monitoring wells.
(5) Highly portable.

Disadvantages:
(1) Large gas volumes and long cycles are necessary for deep operation.
(2) Pumping rates cannot match rates of submersible, suction or jet pumps.
(3) Commercial units relatively expensive - approximately $1000 for units currently available.

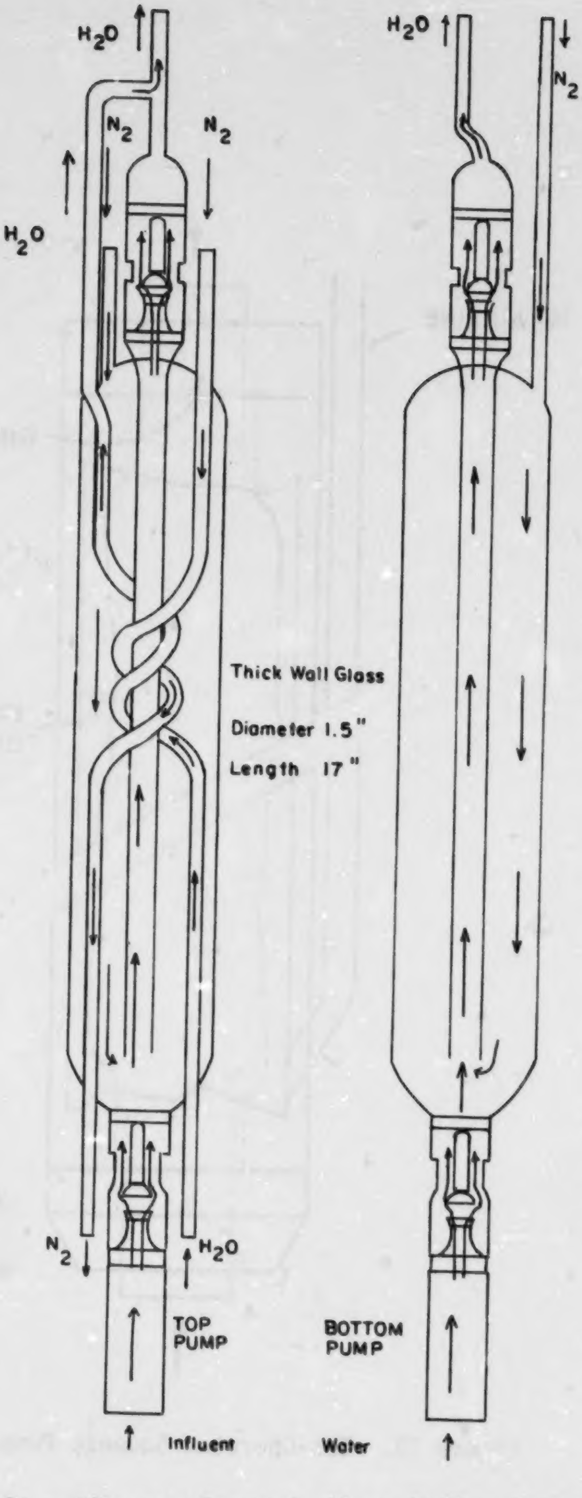

H_2O
N_2
N_2
H_2O
H_2O
N_2
Thick Wall Glass
Diameter 1.5"
Length 17"
N_2
H_2O
TOP PUMP
BOTTOM PUMP
Influent
Water

Figure 21. Nitrogen Powered, Glass-Teflon Pump (9)

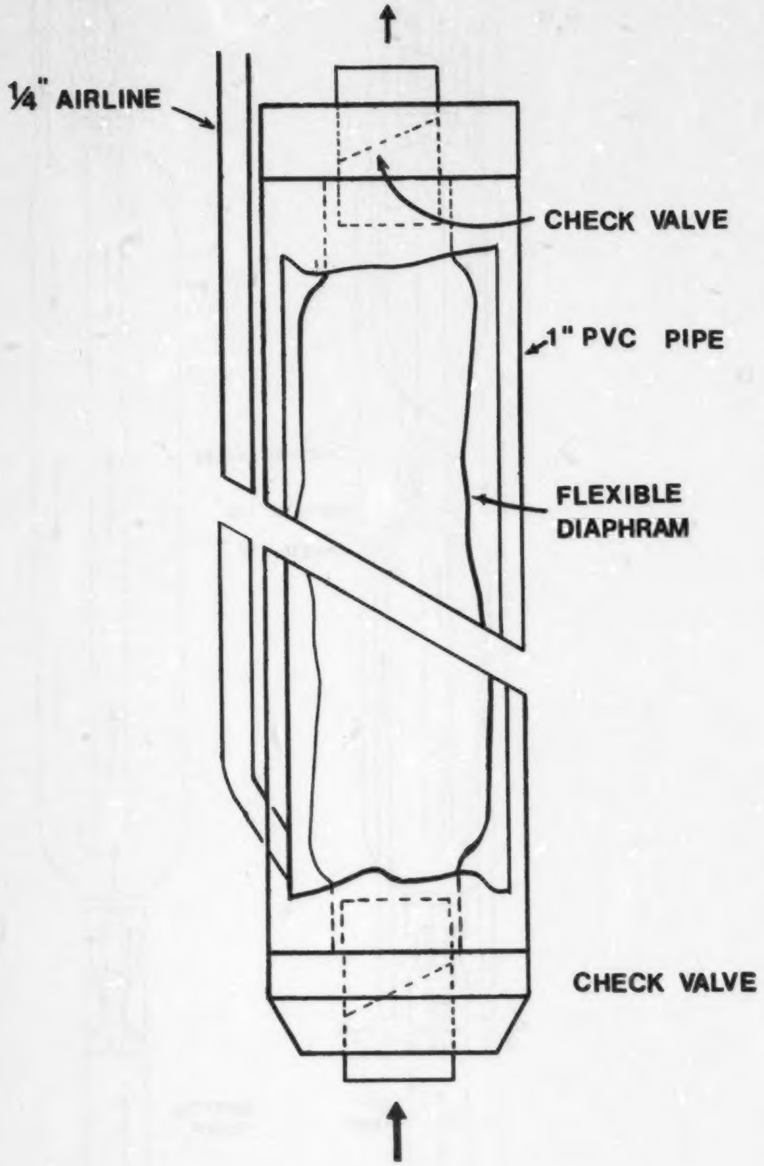

¼" AIRLINE
CHECK VALVE
1" PVC PIPE
FLEXIBLE DIAPHRAM
CHECK VALVE

Figure 22. Gas-Operated Squeeze Pump (7) (10)

Gas-Driven Piston Pump

A modification of pumps developed by Bianchi (11) and Smith (12) has been reported by Signor (13) for collecting samples from wells of two-inch or larger diameter. The pump is a double-acting piston type operated by compressed gas (Figure 23). The driving gas enters and exhausts from the gas chambers between the two pistons and the intermediate connector that joins them. Built-in check valves at each end of the pump allow water to enter the cylinders on the suction stroke and to be expelled to the surface on the pressure stroke. Present designs are constructed basically of stainless steel, brass and PVC. Pumping rates vary with the pumping head but pumping rates of 2.5 to 8 gallons/hour have been noted at 100 feet of pumping head.

Advantages:
(1) Isolates the sample from the operating gas.
(2) Requires no electrical power source.
(3) Operates continuously and reliably over extended periods of time.
(4) Uses compressed gas economically.
(5) Can be operated at pumping heads in excess of 500 meters.

Disadvantages:
(1) Relatively expensive - in excess of $3000 for the continuously operating unit.
(2) Particulate material may damage or inactivate pump unless the suction line is filtered.
(3) Low pumping rates.

Special Sampling Considerations For Organic Samples (3) (14)

Sampling for organic parameters is a new and in no way, a routine procedure at this time. The equipment and methods in current use are largely in the research state. The concepts are fundamental, however, and any particular item can be modified to suit actual field needs. Furthermore, these rather expensive and sophisticated procedures may not be necessary for sampling or monitoring all areas. New techniques and materials are continuously being examined, which in turn should lead to the development of more sophisticated yet more economical sampling methods. The points that must be kept in mind include the potential for sample contamination and the extremely fine detail, subject to expert rebuttal, that may be necessary in a legal action.

Grab Samples--

Grab samples of ground water for non-volatile organic analysis may be collected by utilizing the system shown in Figure 24 where the sampled water contacts only sterile glass and Teflon, and the water table is within suction lift. The sampled water is then carefully transferred to appropriate glass sample containers for shipment to the laboratory.

For sampling at depths beyond suction lift, a noncontaminating submersible pump should be used to pump the ground water to the surface, through scrupulously cleaned Teflon tubing, directly into appropriate sample containers.

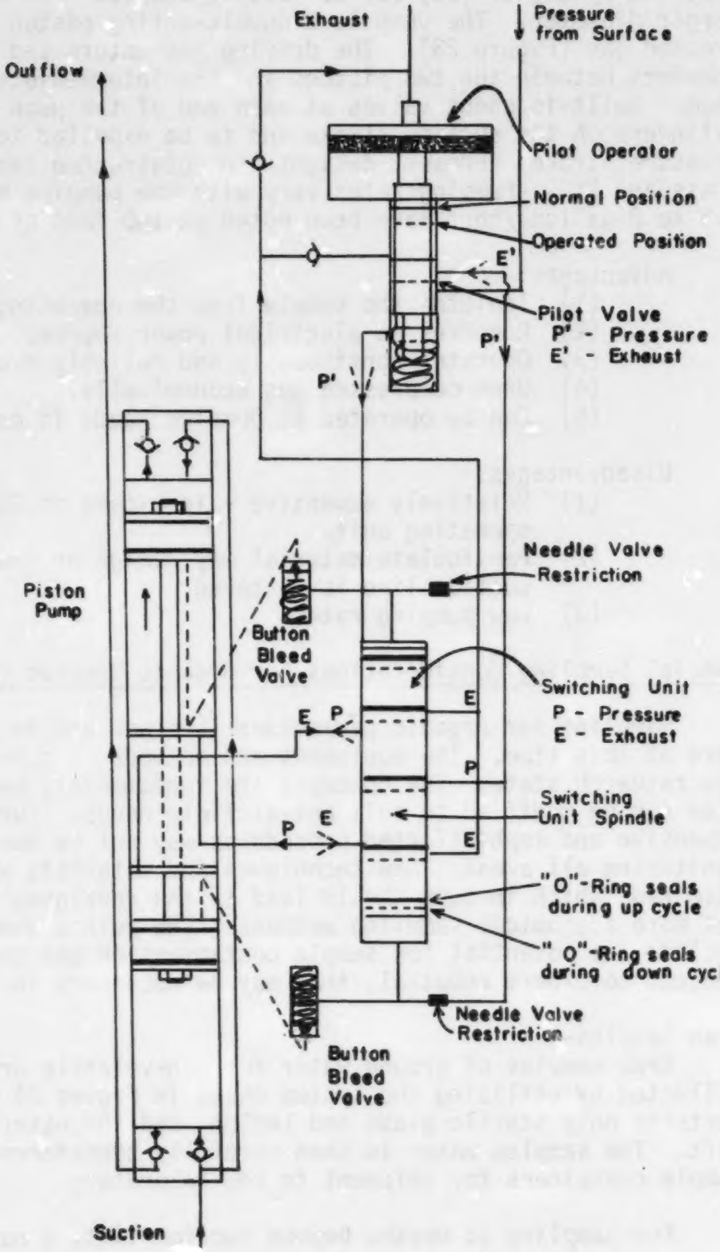

Exhaust
Pressure from Surface
Outflow
Pilot Operator
Normal Position
Operated Position
E'
Pilot Valve
P' - Pressure
E' - Exhaust
P'
P'
Needle Valve Restriction
Piston Pump
Button Bleed Valve
Switching Unit
P - Pressure
E - Exhaust
E
E
P
P
Switching Unit Spindle
P
E
E
"O"-Ring seals during up cycle
"O"-Ring seals during down cycle
Needle Valve Restriction
Button Bleed Valve
Suction

Figure 23. Gas-Driven Piston Pump (13)

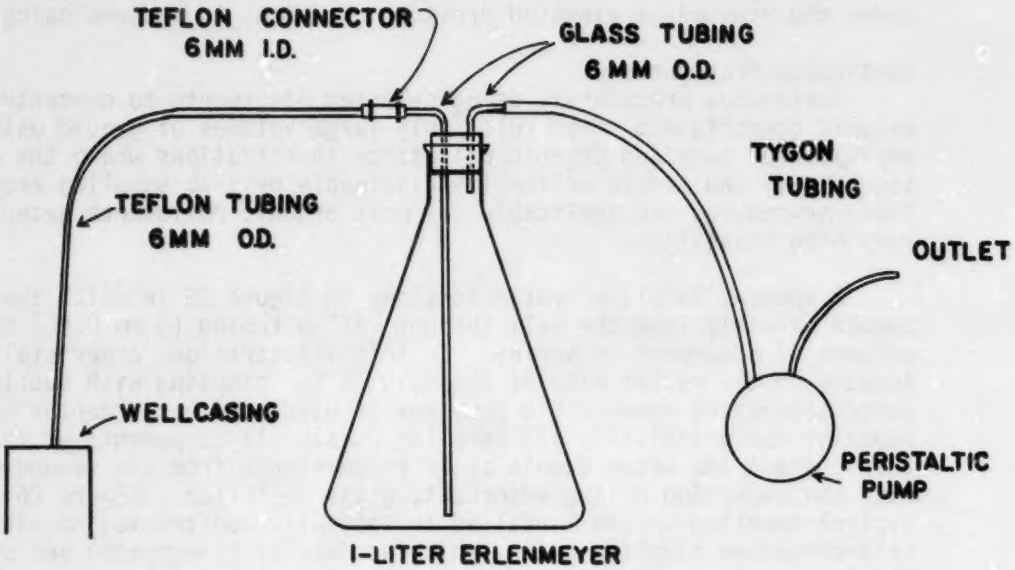

TEFLON CONNECTOR
6MM I.D.
GLASS TUBING
6 MM O.D.
TYGON
TUBING
TEFLON TUBING
6MM O.D.
OUTLET
WELLCASING
PERISTALTIC
PUMP
I-LITER ERLENMEYER

Figure 24. System for Grab Sampling (3)

The most commonly employed sample containers are 40 ml glass vials for analyses requiring small sample volumes, such as total organic carbon, and one-gallon jugs for analyses requiring relatively large volumes, such as extractable organics. Both types of containers are equipped with Teflon-lined screw caps. Like all glassware used in the sampling and analytical procedures, sample containers are thoroughly cleaned prior to use by washing with detergent, rinsing extensively with tap water followed by high purity deionized water and heating to 560° for two hours.

Grab samples of ground water to be analyzed for highly volatile organics by the Bellar-Lichtenberg volatile organic analysis (VOA) method (15) are usually obtained by means of a Teflon bailer noted in Figure 18. Use of the systems described previously is less desirable than bailers for VOA samples because of possible stripping of highly volatile constituents from the sample under the reduced or elevated pressure occurring in systems using pumps.

Continuous Procedures--

Continuous procedures, using selected adsorbents to concentrate and recover organic constituents from relatively large volumes of ground water, may be employed for sampling organic pollutants in situations where the analytical sensitivity and sample uniformity attainable by grab sampling are inadequate. These procedures are applicable for most organic pollutants except those of very high volatility.

A special sampling system is shown in Figure 25 in which the water is pumped directly from the well through Teflon tubing (6 mm O.D.) to two glass columns of adsorbent in series. In this illustration, a peristaltic pump is located on the outlet side of the columns for sampling with suction lift. A noncontaminating submersible pump may be used at greater depths and may be superior for practically all sampling uses. All components of the systems that contact the water sample prior to emergence from the second column are, with the exception of the adsorbent, glass or Teflon. Figure 26 shows a typical sampling system installed in specially constructed housings to form self-contained sampling units, which are easily transported and set up in the field.

Columns prepared from macroreticular resins, activated carbon, and polyamide particles have been employed in sampling systems. Of these materials, macroreticular resin (XAD-2, Rohm and Haas Company, Philadelphia, Pennsylvania) has been the most convenient and generally useful and is the current adsorbent of choice.

Sampling is conducted by continuously pumping ground water through the sampling systems at flow rates usually ranging from 10 to 30 ml/min. The volumes sampled are dependent on the desired sensitivity of analysis. For analysis by modern gas chromatographic techniques, sampling of 50 liters of water is sufficient to provide a sensitivity of at least one μg/liter (1 ppb) for almost all compounds of interest. Volumes sampled are determined by measuring the water leaving the sampling systems in calibrated waste receivers.

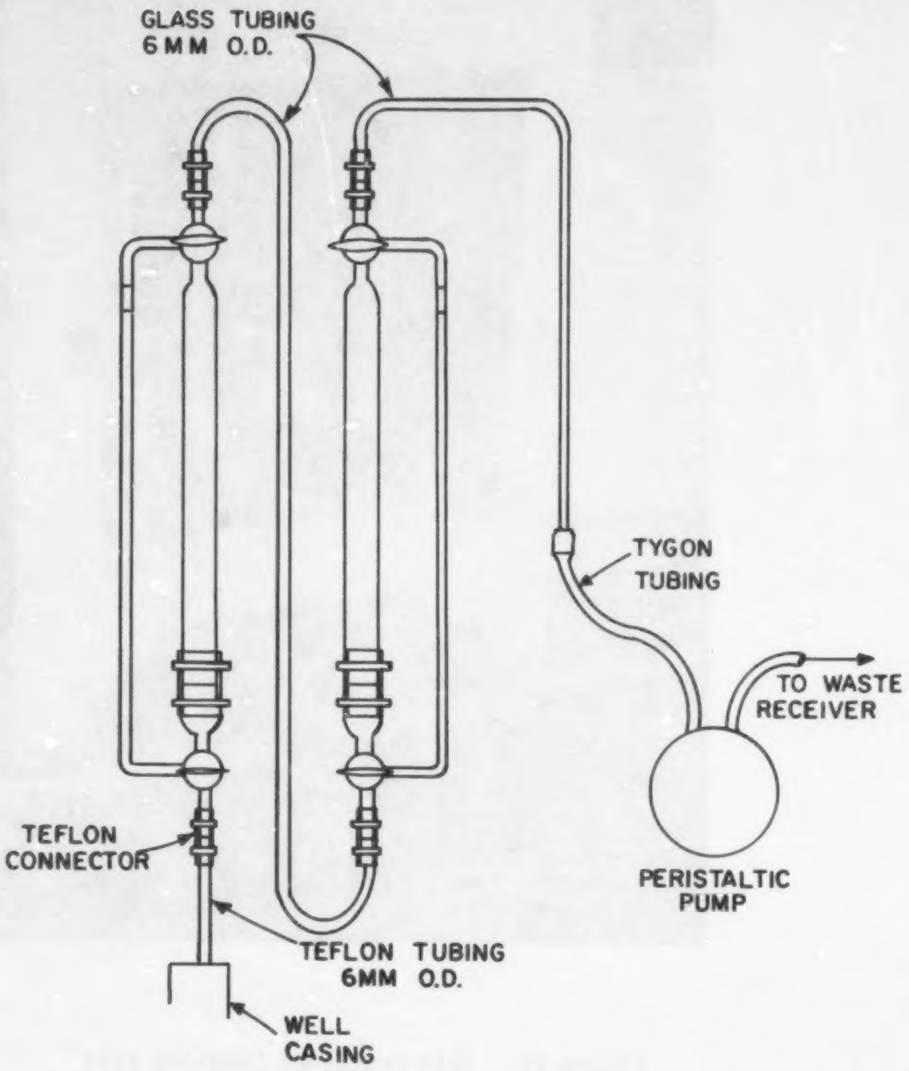

GLASS TUBING
6MM O.D.
TYGON
TUBING
TO WASTE
RECEIVER
PERISTALTIC
PUMP
TEFLON
CONNECTOR
TEFLON TUBING
6MM O.D.
WELL
CASING

Figure 25. Continuous Sampling System for Organics (3)

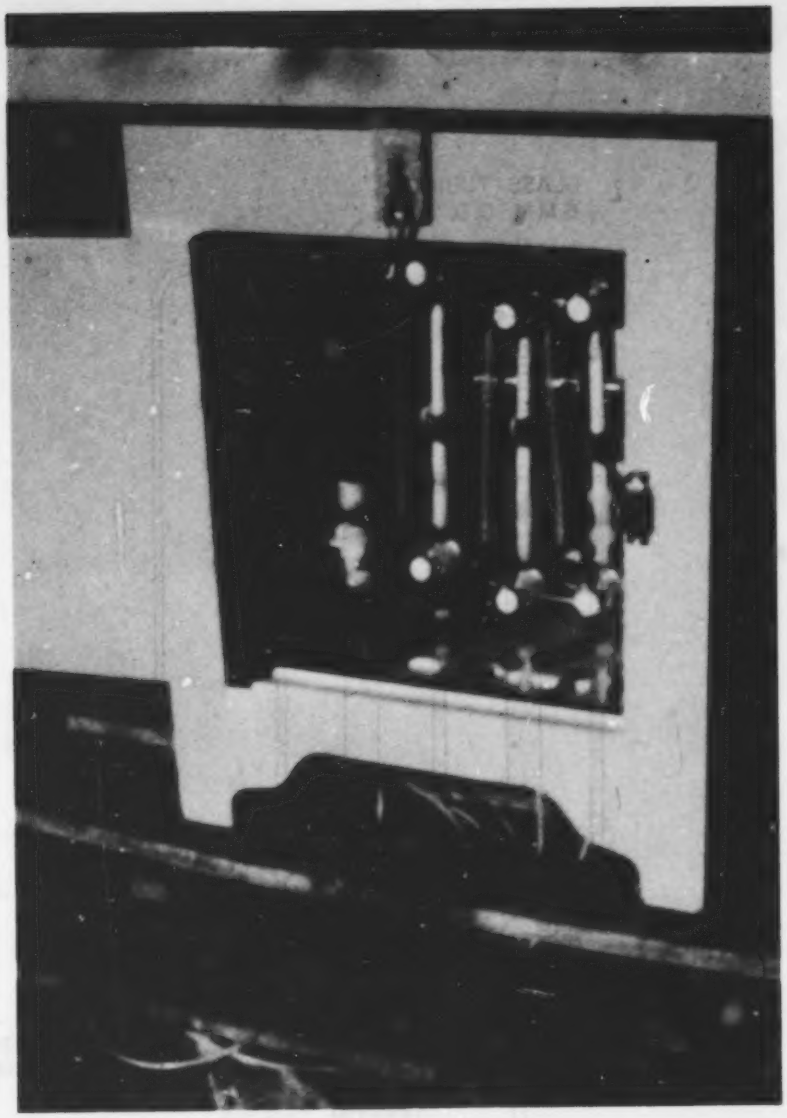


Figure 26. Self-Contained Sampling Unit for Organics (14)

Volatile Organics In The Unsaturated Zone (3)--

For investigations pertaining to organic pollution of ground water, it is often desirable to sample water in the unsaturated zone to detect and follow the movement of pollutants that are migrating toward the water table. This is a particularly difficult task in the case of highly volatile compounds, including the low molecular weight chlorinated hydrocarbons such as trichloroethylene. A number of these compounds are widely used and released into the environment in significant quantities, exhibit some form of toxicity, particularly carcinogenicity, and are being increasingly implicated in cases of ground water pollution.

Soil-water samples may be collected using the device depicted in Figure 27, which consists of a sampler, a purging apparatus, and a trap connected to sources of nitrogen gas and vacuum. The soil-solution sampler consists of a 7/8 in. O.D. (2.2 cm) porous ceramic cup, a length of 3/4 in. O.D. Teflon or PVC pipe and a Teflon stopper fitted with 3 mm O.D. Teflon exhaust and collection tubes. The length of the pipe is dictated by the depth of sampling desired, which is limited to a maximum of about 20 feet. The device is basically a suction lysimeter and, consequently, suffers from the limitations of such equipment.

The purging apparatus and trap are parts of the Tekmar LSC-1 liquid-sample concentrator to which have been added Teflon valves and "Tape-Tite" connectors. The purging apparatus is borosilicate glass, while the trap consists of Tenax-GC porous polymer (60/80 mesh), packed in a 2 mm x 28 cm stainless steel tube plugged with silane-treated glass wool. The purge gas is ultra high purity, oxygen-free nitrogen. Vacuum is provided by a peristaltic pump.

Prior to sample collection, the purging apparatus is cleaned with acetone and distilled water and then baked at 105 to 108° for at least an hour. In the field, it is rinsed thoroughly with distilled water between samples with special care being exercised to force the rinse water through the glass frit.

The soil-solution sampler is driven to the bottom of a pre-augered 19 mm (0.75 in) diameter hole. This is done very carefully to insure intimate contact between the ceramic cup and the soil.

Prior to collection of a sample, the exhaust tube is opened to the atmosphere and the collection tube disconnected and pumped to remove any solution that may have leaked into the tube through the porous cup. Then, the collection tube is reconnected to the purging aparatus, the exhaust tube closed with a pinch clamp, and 5 to 10 ml of solution is collected by closing valve C and opening valves A and B (Figure 27). After sample collection, the exhaust tube is opened to remove from the sampler and collect on the trap any of the compounds that may have volatilized in the sampler. Following this procedure, A is closed and C opened. Nitrogen gas is then bubbled through the solution at a rate of 40 ml/min for ten minutes to purge volatile organics from solution. Traps are capped and returned to the laboratory for analysis within six hours of collection or for storage at -20°C for later analysis. Chemical concentrations are determined according to procedures based on the method of Bellar and Lichtenberg.

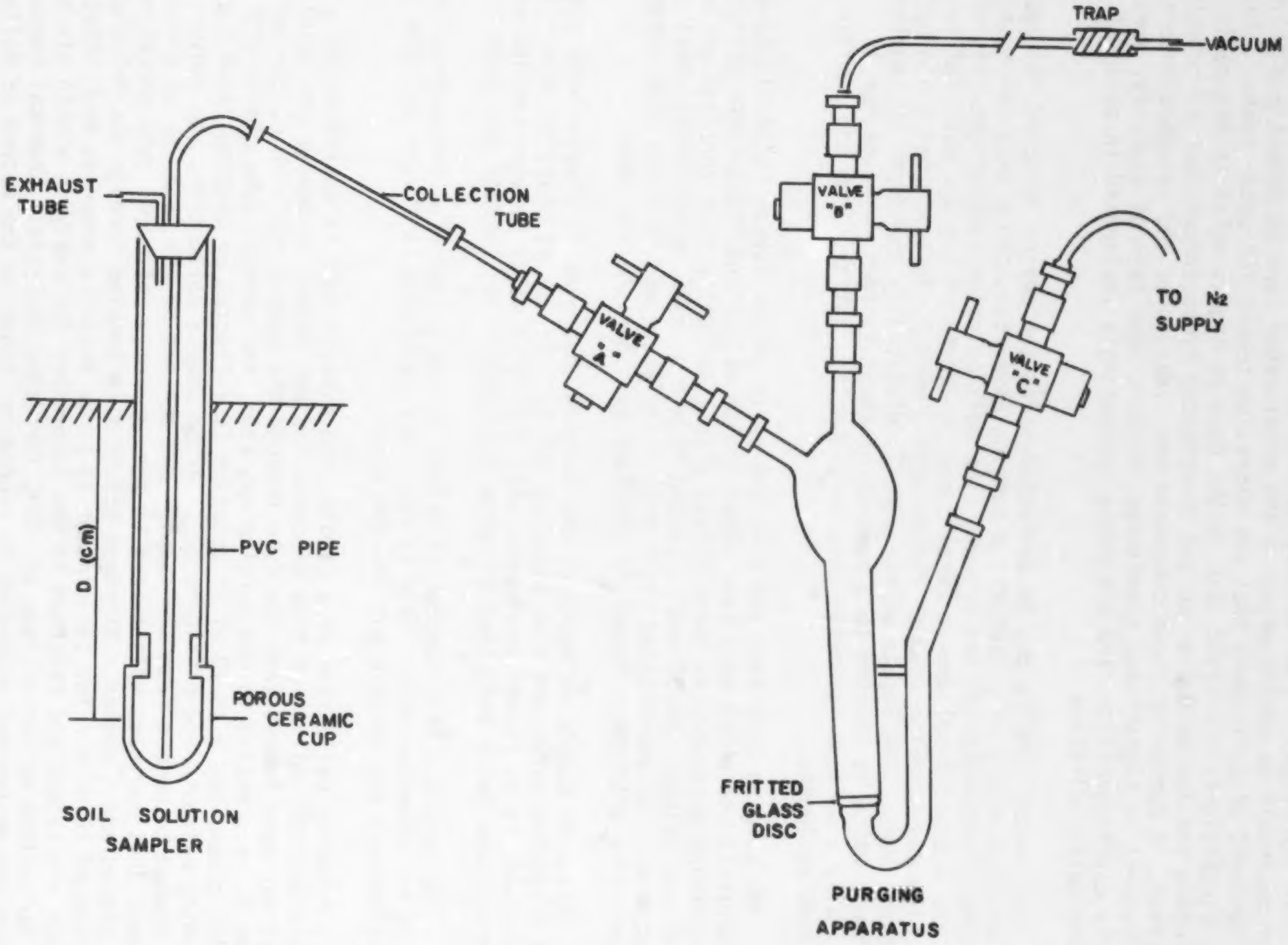

TRAP
VACUUM
EXHAUST TUBE
COLLECTION TUBE
VALVE "B"
VALVE "A"
VALVE "C"
TO N2 SUPPLY
D (cm)
PVC PIPE
POROUS CERAMIC CUP
SOIL SOLUTION SAMPLER
FRITTED GLASS DISC
PURGING APPARATUS

Figure 27. Soil-Water Sampling Device for Volatile Organics (3)

FIELD TESTS AND PRESERVATION

Type of information required and its intended use determines the field analyses and sample preservation necessary. Because of the slow rate of change in many parameters, it is often possible to establish ground water quality by collecting samples in the field and transporting to a laboratory for subsequent analyses. As noted earlier, other parameters may change very rapidly when the sample is removed from its natural subsurface environment into another environment of different temperature, pressure, light, substrate or oxygen conditions.

Samples should be preserved at low temperatures in the dark during transport to the laboratory for analysis. Appropriate chemical preservation should be performed in the field for various analytical parameters at the time of sampling. Regardless of the method of preservation, analyses should be performed as soon after sampling as is practicably possible in accordance with EPA and Standard Methods holding times.

Inorganic and Routine Organic Chemical Parameters (16)

Complete and unequivocal preservation of samples is a practical impossibility. Regardless of the nature of the sample, complete stability for every constituent can never be achieved. At best, preservation techniques can only retard the chemical and biological changes that inevitably continue after the sample is removed from the parent source.

Methods of preservation are generally limited to pH control, chemical addition, refrigeration, and freezing and are intended generally to (1) retard biological action, (2) retard hydrolysis of chemical compounds and complexes and (3) reduce volatility of constituents. Various preservatives that may be used to retard changes in samples are as follows:

Preservative	Action	Applicable to:
$HgCL_2$	Bacterial Inhibitor	Nitrogen forms, phosphorus forms
Acid (HNO_3)	Metals solvent, prevents precipitation	Metals
Acid (H_2SO_4)	Bacterial Inhibitor	Organic samples (COD, oil and grease, organic carbon)
	Salt formation with organic bases	Ammonia, amines
Alkali (NaOH)	Salt formation with volatile compounds	Cyanides, organic acids
Refrigeration	Bacterial Inhibitor	Acidity - alkalinity, organic materials, BOD, color, odor, organic P, organic N, carbon, etc., biological organism (coliform, etc.)

In summary, refrigeration at temperatures near freezing or below is the best preservation technique available, but it is not applicable to all types of samples.

The recommended choice of preservatives, sample volumes required, type of sample container, and holding time for various constituents is given in Table 1 which is taken from USEPA recommended methods for chemical analysis (2).

Organic Parameters

Because organic analyses are tedious, time-consuming and require sophisticated laboratory equipment, all ground water samples should be transported to a laboratory for analysis. Small grab samples should be quick-frozen on dry ice, with care being exercised to allow adequate space in the container for expansion during freezing. For large samples, containers should be topped-off to exclude air, packed in ice, and shipped to the laboratory as soon as possible. Frozen samples can be stored at -40°C until analyzed; analysis of unfrozen samples should be initiated immediately upon arrival at the laboratory.

Grab samples to be analyzed for highly volatile organics and collected by the sterilized Teflon bailer, should be carefully poured from the bailer into clean serum bottles or screw-cap vials of appropriate size (usually 40 - 125 ml), avoiding turbulence, which might result in the loss of volatile organics and/or excessive oxygenation of the samples. The containers should be topped-off to avoid gas space and tightly closed with Teflon-lined septums held in place by aluminum crimp-on seals or open top screw caps. The sealed VOA samples are packed in ice and returned to the laboratory for analysis at the earliest convenient time.

When sampling is completed with resin columns, the columns should be sealed while completely filled with sample water and the sampling units should be immediately returned to the laboratory for disassembly and elution of the accumulated organic pollutants from the adsorbent. Similarly prepared columns should be processed along with the sampling columns to provide blank extracts for quality control. Although notabsolutely necessary, columns should be kept cool by refrigeration or icing during transit when possible (3).

Microbiological Parameters

Collection of ground water samples for microbiological analyses involves the same general considerations as for obtaining samples for chemical analyses, but also involves the special considerations to ensure representative, uncontaminated samples.

The proper collection, preservation, storage and analysis of water samples for microbiological parameters is explained in other publications (15), (16), (17), (18) which should also be consulted. For bacteriological analyses sample bottles must be at least 125 ml volume for adequate sampling and for good mixing, must be sterilized and must be chemically clean. Wide-mouth borosilicate glass bottles with screw-cap or ground-glass stoppers or heat-resistant plastic bottles are recommended if they do not produce toxic or nutritive

TABLE 1. RECOMMENDATION FOR SAMPLING AND PRESERVATION OF SAMPLES ACCORDING TO MEASUREMENT[a]

Measurement	Vol. Req. (ml)	Container[b]	Preservative	Holding Time[c]
Physical Properties				
Color	50	P,G	Cool, 4°C	24 Hrs.
Conductance	100	P,G	Cool, 4°C	24 Hrs.[d]
Hardness	100	P,G	Cool, 4°C HNO_3 to pH<2	5 Mos.[e]
Odor	200	G only	Cool, 4°C	24 Hrs.
pH	25	P,G	Det. on site	6 Hrs.
Residue				
Filterable	100	P,G	Cool, 4°C	7 Days
Non-Filterable	100	P,G	Cool, 4°C	7 Days
Total	100	P,G	Cool, 4°C	7 Days
Volatile	100	P,G	Cool, 4°C	7 Days
Settleable Matter	1000	P,G	None Req.	24 Hrs.
Temperature	1000	P,G	Det. on site	No Holding
Turbidity	100	P,G	Cool, 4°C	7 Days
Metals				
Dissolved	200	P,G	Filter on site HNO_3 to pH<2	6 Mos.[e]
Suspended	200		Filter on site	6 Mos.
Total	100	P,G	HNO_3 to pH<2	6 Mos.[e]

(continued)

TABLE 1. (continued)

Measurement	Vol. Req. (ml)	Container[b]	Preservative	Holding Time[c]
Mercury Dissolved	100	P,G	Filter on site HNO_3 to pH<2	38 Days (Glass) 13 Days (Hard Plastic)
Total	100	P,G	HNO_3 to pH<2	38 Days (Glass) 13 Days (Hard Plastic)
Inorganics, Non-Metallics				
Acidity	100	P,G	None Req.	24 Hrs.
Alkalinity	100	P,G	Cool, 4°C	24 Hrs.
Bromide	100	P,G	Cool, 4°C	24 Hrs.
Chloride	50	P,G	None Req.	7 Days
Chlorine	200	P,G	Det. on site	No Holding
Cyanides	500	P,G	Cool, 4°C NaOH to pH 12	24 Hrs.
Fluoride	300	P,G	None Req.	7 Days
Iodide	100	P,G	Cool, 4°C	24 Hrs.
Nitrogen				
Ammonia	400	P,G	Cool, 4°C H_2SO_4 to pH<2	24 Hrs.
Kjeldahl, Total	500	P,G	Cool, 4°C H_2SO_4 to pH<2	24 Hrs.[f]
Nitrate plus Nitrite	100	P,G	Cool, 4°C H_2SO_4 to pH<2	24 Hrs.[f]
Nitrate	100	P,G	Cool, 4°C	24 Hrs.
Nitrite	50	P,G	Cool, 4°C	48 Hrs.

(continued)

TABLE 1. (continued)

Measurement	Vol. Req. (ml)	Container(b)	Preservative	Holding Time(c)
Dissolved Oxygen Probe	300	G only	Det. on site	No Holding
Winkler	300	G only	Fix on site	4-8 Hrs.
Phosphorus Ortho-phosphate, Dissolved	50	P,G	Filter on site Cool, 4°C	24 Hrs.
Hydrolyzable	50	P,G	Cool, 4°C H_2SO_4 to pH<2	24 Hrs.(f)
Total	50	P,G	Cool, 4°C H_2SO_4 to pH<2	24 Hrs.(f)
Total, Dissolved	50	P,G	Filter on site Cool, 4°C H_2SO_4 to pH<2	24 Hrs.(f)
Silica	50	P only	Cool, 4°C	7 Days
Sulfate	50	P,G	Cool, 4°C	7 Days
Sulfide	500	P,G	2 ml zinc acetate	24 Hrs.
Sulfite	50	P,G	Det. on site	No Holding
Routine Organics				
BOD	1000	P,G	Cool, 4°C	24 Hrs.
COD	50	P,G	H_2SO_4 to pH<2	7 Days(f)
Oil & Grease	1000	G only	Cool, 4°C H_2SO_4 or HCL to pH<2	24 Hrs.
Organic Carbon	25	P,G	Cool, 4°C H_2SO_4 or HCL to pH<2	24 Hrs.
Phenolics	500	G only	Cool, 4°C H_3PO_4 to pH<4 1.0 g $CuSO_4$/1	24 Hrs.

(continued)

TABLE 1. (continued)

Measurement	Vol. Req. (ml)	Container[b]	Preservative	Holding Time[c]
MBAS	250	P,G	Cool, 4°C	24 Hrs.
NTA	50	P,G	Cool, 4°C	24 Hrs.

a. A general discussion on sampling water and industrial wastewater may be found in ASTM, Part 31, p. 72-82 (1976) Method D-3370.

b. Plastic (P) or Glass (G). For metals polyethylene with a polypropylene cap (no liner) is preferred.

c. It should be pointed out that holding times listed above are recommended for properly preserved samples based on currently available data. It is recognized that for some sample types, extension of these times may be possible while for other types, these times may be too long. Where shipping regulations prevent the use of the proper preservation technique or the holding time is exceeded, such as the case of a 24-hour composite, the final reported data for these samples should indicate the specific variance.

d. If the sample is stabilized by cooling, it should be warmed to 25°C for reading, or temperature correction made and results reported at 25°C.

e. Where HNO_3 cannot be used because of shipping restrictions, the sample may be initially preserved by icing and immediately shipped to the laboratory. Upon receipt in the laboratory, the sample must be acidified to a $pH < 2$ with HNO_3 (normally 3 ml 1:1 HNO_3/liter is sufficient). At the time of analysis, the sample container should be thoroughly rinsed with 1:1 HNO_3 and the washings added to the sample (volume correction may be required).

f. Data obtained from National Enforcement Investigations Center-Denver, Colorado, support a four-week holding time for this parameter in Sewerage Systems. (SIC 4952).

materials when sterilized. If ground waters are suspected of containing >0.01 mg/liter concentrations of toxic heavy metals such as copper, nickel, or zinc, etc., 0.3 ml of a 15 percent solution of ethylendiaminetetracetic acid (EDTA) tetrasodium salt, should be added for each 125 ml sample column prior to sterilization. Sample bottles should be protected from contamination during transit by covering the tops and necks with aluminum foil or kraft paper before sterilization. Sterilization may be accomplished by autoclaving at 121°C for 15 minutes or heating in a hot air oven at 170°C for not less than two hours.

There are several different methods for obtaining a ground water sample. Each of these methods differ in their advantages and disadvantages for obtaining samples for microbiological analyses.

The majority of ground water samples are obtained using preexisting wells which have existing in-place pumps. This limits the precautions the sampler can take to ensure a non-contaminated sample. Samples should be obtained from outlets as close as possible to the pump and should not be collected from leaky or faulty spigots or spigots that contain screens or aeration devices. The pump should be pumped to waste for 5 - 10 minutes before the sample is collected. A steady-flowing water stream at moderate pressure is desirable in order to prevent splashing and dislodging particles in the faucet or water line.

To collect the sample, remove the cap or stopper carefully from the sample bottle. Do not lay the bottle closure down or touch the inside of the closure. Avoid touching the inside of the bottle with your hands or the spigot. The sample bottle should not be rinsed out and it is not necessary to flame the spigot. The bottle should be filled directly to within 2.5 cm (1 inch) from the top. The bottle closure and closure-covering should be replaced carefully and the bottle should be placed in a cooler (4 - 10°C) unless the sample is going to be processed immediately in the field.

If a well does not have an existing in-place pump, samples can be obtained by either using a portable surface or submersible pump or by using a bailer. Each method presents special problems in obtaining an uncontaminated sample.

The main problem in using a sterilized bailer is obtaining a representative sample of the aquifer water without pumping or bailing the well beforehand to exchange the water in the bore for fresh formation water. This is difficult since such pre-sampling activities must be carried out in such a way as to not contaminate the well. Care must also be taken with bailers to not contaminate the sample with any scum on the surface of the water in the well. This is usually done by using a weighted, sterilized sample bottle suspended by a nylon rope and lowering the bottle rapidly to the bottom of the well.

The use of portable pumps provides a way of pumping-out a well before sampling and thus providing a more representative sample, but presents a potential source of contamination if the pumping apparatus cannot be sterilized beforehand. The method of sterilization will depend on what other samples are taken from the well since the use of many disinfectants may not be feasible if the well is also sampled for chemical analyses. If disinfection is not ruled out by other considerations, a method of sterilizing a submersible pump system is to submerge the pump, and any portion of the pump tubing which will be in contact with the well water, into a disinfectant solution and circulating the disinfectant through the pump and tubing for a recommended period of time.

The most widely used method of disinfection due to its simplicity is chlorination. Chlorine solutions may be easily prepared by dissolving either calcium or sodium hypochlorite in water. Calcium hypochlorite, $(CaOCl)_2$, is available in a granular or tablet form usually containing about 70 percent of available chlorine by weight and should be stored under dry and cool conditions. Sodium hypochlorite, NaOCl, is available only in liquid form and can be bought in strengths up to 20% available chlorine. In its most available form, household laundry bleach, it has strength of about 5 percent available chlorine, but should not be considered to be full strength if it is more than 60 days old. The original percentage of available chlorine will be on the label.

Table 2 gives the quantities of either calcium hypochlorite or laundry bleach required to make 100 gallons of disinfectant solution of various concentrations. Fresh chlorine solutions should frequently be prepared because the strength will diminish with time. The proper strength to use in disinfection is dependent upon many factors including pH and temperature. As a rule of thumb, hypochlorite solutions of 50-200 ppm available chlorine and a contact time of 30 minutes should be effective at pH ranges of 6-8 and temperatures of greater than 20°C. After disinfection the pump should be carefully placed in the well and then pumped to waste until the chlorine is thoroughly rinsed from the pump system.

If the pump cannot be disinfected, then the pump and tubing should be carefully handled to avoid gross surface contamination and the well should be pumped for 3-10 bore volumes before taking a sample. It may be desirable after pumping to pull the pump and take the sample with a sterile bailer.

In those cases where the water level in the well is less than 20 to 30 feet below the surface, a surface vacuum-pumping system can be used for flushing out the well and withdrawing a sample. An ideal apparatus for this is depicted in Figure 28. This apparatus consists of two lengths of tubing which are sterilizable by autoclaving and a portable vacuum system. The two tubing lengths which are attached side-by-side to each other, are sterilized in the laboratory in large covered containers. In the field they are lowered into a well using sterile gloves, attached to a vacuum system, and the well is pumped to waste for 3-10 bore volumes with the bypass system. Then the well is sampled by drawing water into a sterile vacuum flask on the inlet side of the pump. Large volume sampling for viruses or pathogenic bacteria can be accomplished by substituting filters or columns with various absorbents in place of the vacuum flask.

Standing water is prevented from entering the sampling tubing upon insertion into the well by making the sampling tube a few feet shorter than the flushing tubing and turning on the pump to the flushing system as the tubing is put into the well.

TABLE 2. QUANTITIES OF CALCIUM HYPOCHLORITE, (70 PERCENT) AND HOUSEHOLD LAUNDRY BLEACH (5 PERCENT) REQUIRED TO MAKE 100 GALLONS OF DISINFECTANT SOLUTION

Desired Chlorine Strength	Dry Calcium Hypochlorite, lb.	5% Household Bleach, Quarts
50 ppm	0.07	0.4
100 ppm	.14	0.8
150 ppm	.20	1.2
200 ppm	.30	1.6

To sample wells using this type of system requires a relatively large autoclave, several sets of sampling tubing, and of course, relatively shallow ground water.

Springs are unlikely to yield representative samples of an aquifer due to surface contamination close to a spring's discharge unless the spring has an extremely fast flow and the outlet is protected from surface contamination.

Lastly, interpretation of analytic results may be difficult in some cases since surface contamination of wells due to poor drilling and completion practices is common. In cases where drinking water supplies are involved, a thorough inspection of the well is required to eliminate surface contamination down the well bore as a source of contaminants. Disinfection of the well by approved methods (21), (22) and resampling may be advisable, if disinfection will not affect the well for other sampling purposes.

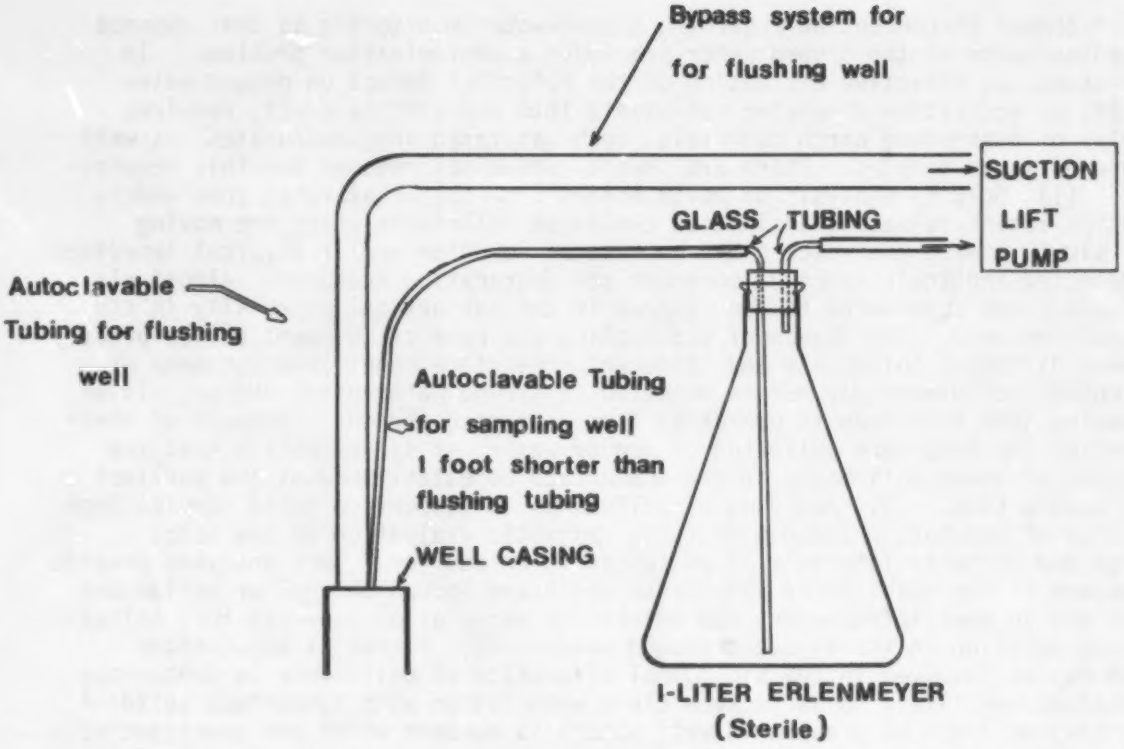

Bypass system for
for flushing wall
SUCTION
LIFT
PUMP
GLASS TUBING
Autoclavable
Tubing for flushing
well
Autoclavable Tubing
for sampling well
1 foot shorter than
flushing tubing
WELL CASING
1-LITER ERLENMEYER
(Sterile)

Figure 28. System for Microbiological Sampling of Wells Using a Suction-Lift Pump (6)

SECTION 7

SAMPLING SUBSURFACE SOLIDS

GENERAL REQUIREMENTS

A common misconception regarding ground-water monitoring is that absence of contaminants in the ground water precludes a contamination problem. In many cases, an effective evaluation of the potential impact on ground water quality of activities releasing pollutants into the earth's crust, requires samples of subsurface earth materials, both saturated and unsaturated, as well as ground water samples. There are several principal reasons for this requirement. (1) Only by analysis of earth solids from the unsaturated zone underlying pollutant-releasing activities can those pollutants which are moving very slowly toward the water table because of sorption and/or physical impediment be detected and their rates of movement and degradation measured. Almost all pollutants are attenuated to some degree in the subsurface, especially in the unsaturated zone. The degree of attenuation and rate of movement varies greatly between different pollutants and different subsurface conditions but many of the mobile pollutants may not be detected in ground water until the activities releasing them have been in operation for protracted periods. Because of their potential for long-term pollution of ground water, it is imperative that the behavior of these pollutants in the subsurface be established at the earliest practicable time. (2) Analyses of pollutants in subsurface solid samples from the zone of saturation are needed for a realistic evaluation of the total extent and probable longivity of pollution in an aquifer. Such analyses provide a measure of the quantity of pollutants which are sorbed on aquifer solids and which are in equilibrium with, and in essence serve as a reservoir for, pollutants in solution in the adjacent ground water. (3) Microbial populations which may be involved in the biological alteration of pollutants in subsurface formations are likely to be in such close association with subsurface solids that they will not be present in well waters in numbers which are quantitatively indicative of their presence in the formations; hence, analysis of subsurface solids are needed for accurate evaluation of such populations. (4) Even when the best well construction and ground-water sampling procedures are used, it is difficult to completely eliminate the possibility that contaminating surface microbes may be present in ground-water samples. Solids taken from the interior of cores carefully obtained from the zone of saturation probably provide the most authenic samples of aquifer microorganisms that can be obtained.

As with ground water samples, successful sampling of subsurface earth solids requires both acquisition of cores of subsurface solids at desired depths in a manner minimizing potential contamination and proper handling and processing of the core material obtained to insure its integrity and produce samples suitable for determinative analytical procedures.

Although tools for collecting soil or core samples have been used for a number of years in the foundation engineering and geology professions, core sampling for ground water quality investigations has received relatively little attention. There are undoubtedly many procedures developed for the foundation engineering, agriculture and petroleum industries that can be used or modified for ground water quality applications. This section of the manual presents some of the procedures that are currently being used.

ACQUISITION OF CORE SAMPLES

There are a variety of procedures and equipment that have been used to collect earth materials for classification and identification of physical characteristics. Tools as simple as a shovel or backhoe can and have been used and a number of designed samplers have also been used for this purpose. Because of the ability to penetrate greater depths and to maintain the physical integrity of the samples, most designed samplers employ some type of coring mechanism. The most common procedures use a thin-wall steel tube (core barrel) which is forced into the undisturbed soil at the bottom of a bore hole. This is sometimes refered to as drive sampling. Core barrels are generally from one inch to three inches in diameter and 12 to 24 inches long. When the core barrel is retrieved, friction will usually retain the sample inside, at least in most unsaturated materials.

The bore hole can be made with a continuous flight or hollow stem auger, rotary core drill or other drilling method. For water quality analyses, it is generally recommended that the drilling method employed avoid the use of drilling fluids since these greatly increase the potential for sample contamination. Similarly, it is also recommended that core sampling equipment avoid the use of drilling fluids.

Hand-operated soil sampling kits are commercially available that can be used at relatively shallow depths to both open the bore hole and collect a soil core. One such unit contains augers, coring tubes and sufficient drill rod extensions to sample to depths of twenty-five feet (23).

One widely used sampling device is a thin wall tube sampler illustrated in Figure 29. This device consists principally of a head unit threaded to fit standard drill rod and a replaceable thin wall seamless steel tube (23). The most popular tube size is 3 inches O.D. although sizes from 2 inches to 5 inches are available. In some subsurface materials, drag on the inner wall of the tube may cause considerable compression of the sample in unsaturated materials. To reduce this distortion and aid in keeping the sample in the tube during withdrawal from the bore hole, some investigators use a drive shoe on the bottom of the tube that has an inside diameter slightly less than that of the tube.

Another method of minimizing compression of the sample during coring is to wet the inside of the coring tube with distilled water immediately preceding the sampling operation.

Sampling in the saturated zone encompasses a number of additional problems of sample integrity. Maintaining an open bore hole while collecting a core

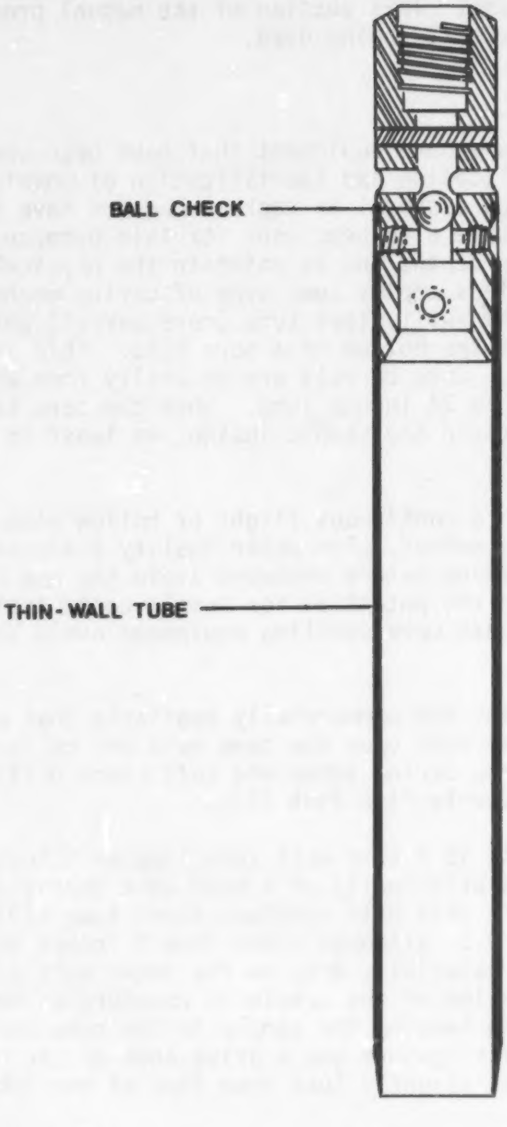

BALL CHECK
THIN-WALL TUBE

Figure 29. Thin Wall Tube Sampler (23)

sample is extremely difficult, especially in fine sand aquifers. Use of a hollow-stem auger can alleviate this problem in many situations but in extreme situations, removal of the auger plug may permit sand to flow up the interior of the auger before the core sample can be taken.

Sampling in a saturated zone also increases problems of contamination. The coring tube must travel through water in the bore hole and this water will almost surely contaminate at least the outside of the core sample. It is necessary, especially for microbial analyses, that the outside of the cores be discarded and that only the interior be used for sample analyses.

For deeper sampling, beyond the practical capability of augers, methods for collecting uncontaminated samples have not been proven. Air drilling with casing hammer offers the potential for opening a bore hole at the greater depths without drilling fluids. However, data is lacking at this time concerning the depth into the undisturbed bottom of the bore hole that is affected by the air drilling. Similarly, limited use has been made of a piston sampler for deeper sampling. The piston sampler employs a sample tube identical to the thin-wall core barrel but drilling fluid pressure is used as the driving force. The sampler sits on the bottom of the borehole at the end of the drill stem. A shear pin maintains the sample tube in an "up" position until a vent plug is dropped down the drillstem to the sampler. Pressure of the drilling fluid then shears the pin, forcing the tube through the bottom of the hole into the undisturbed material below the borehole. Considerable additional work is needed, however, to evaluate the extent of core contamination and to develop optimum methods for avoiding such contamination.

HANDLING AND PROCESSING OF CORE MATERIALS

The procedures to follow in processing a sample will depend on the type of analyses and the situation in the field. Regardless of the types of analyses to be performed, processing should be as soon as possible. When dealing with cores, the core may be processed in the field or if necessary the core may be retained in the core barrel, placed in a sterile plastic bag, sealed, and transported to the laboratory. This procedure works sufficiently well for cores of relatively compact, dry materials, but is not satisfactory for loose or very wet materials which will shift within the core barrel. Recommendations on storage of samples before processing vary widely from maintaining samples at the temperatures at which they are sampled to refrigerating them.

Split tubes or sectioned tubes are sometimes used to collect cores so as to permit access to the core material with minimal disturbance. Dunlap, et al. recommends a single piece coring tube and the use of a hydraulic extruding device when sampling subsurface solids for organics or microorganisms (12). As soon as the core is obtained, the drive shoe, if used, is removed and the sample tube is placed into the extruding device (Figure 30). As the core sample is forced out of the tube, the first 5 to 8 cm (2 - 3 in) are cut off with a sterile scalpel and discarded, or used for analyses of chemical or physical parameters. The center of the cores is then subsampled to obtain material suitable for microbial analysis by pushing a sterile 1.3 cm (0.5 in) I.D. stainless steel tube into the core for about 15 cm (6 in), as shown in Figure 31. The subsample is extruded with a sterile rod into appropriate containers.

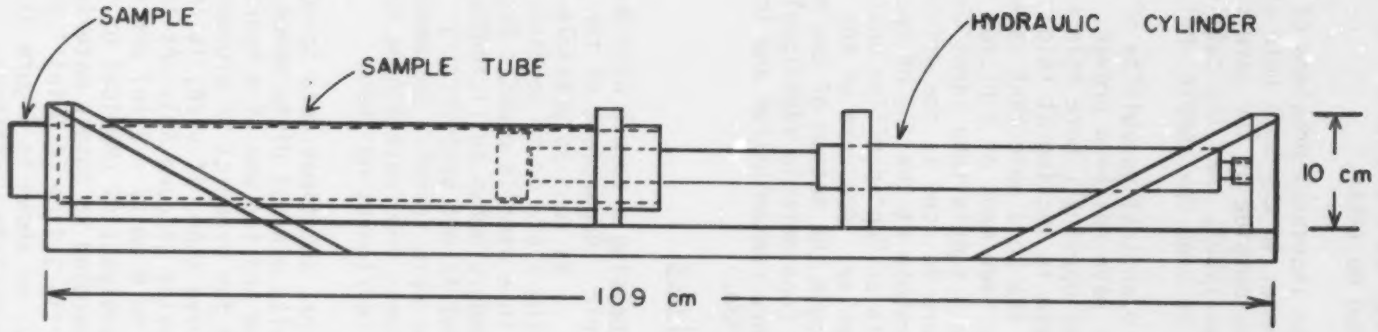

SAMPLE
SAMPLE TUBE
HYDRAULIC CYLINDER
10 cm
109 cm

Figure 30. Core Sample Extruding Device (14)

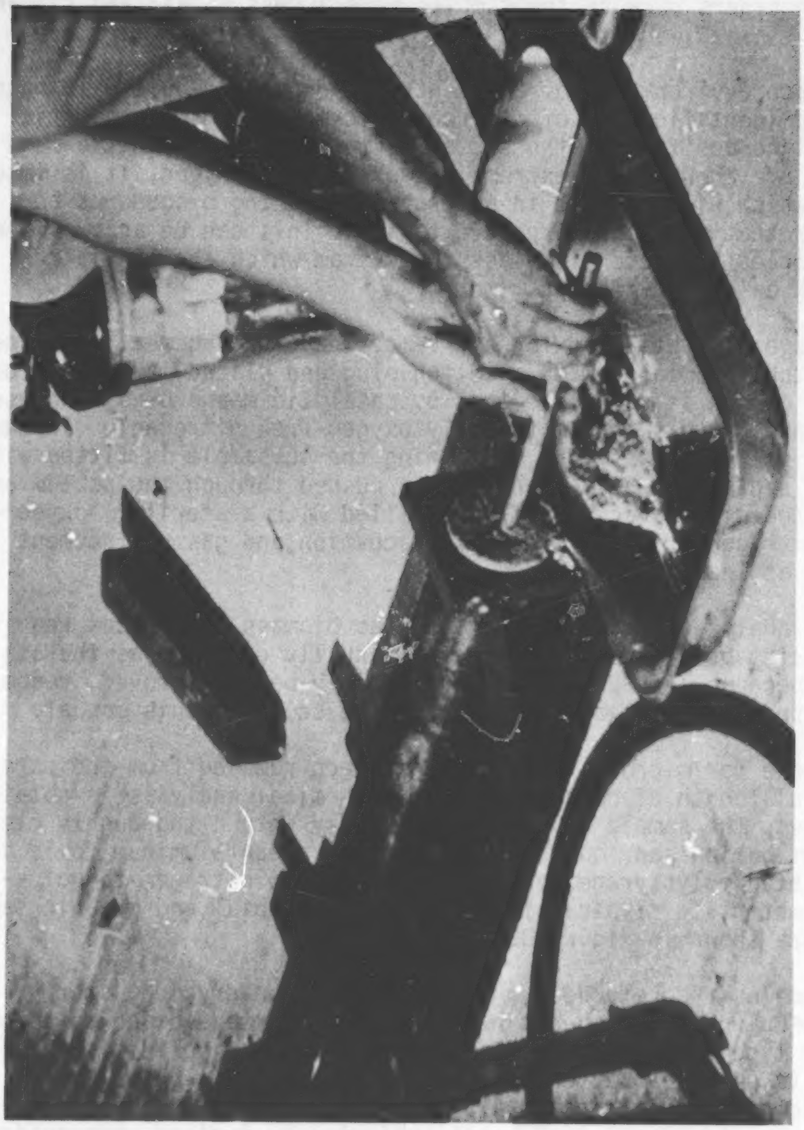


Figure 31. Subsampling a Soil Core (14)

The type of sample container which is used is dependent on the type of analysis to be performed. For culturing of aerobic organisms any sterile container is suitable if analyses are to be performed within a few hours. If there is to be a significant delay before the sample is used, care is exercised to keep the sample in a manner that prevents major changes in the microbial content. Polyethylene bags, which allow the passage of air but not water vapor, are good sample containers because the samples have access to air and yet are kept from drying.

Since subsurface environments of any depth are usually reducing in nature, the enumeration and identification of anaerobic microorganisms is essential if the total microbial composition of the system is to be known. Because many anaerobic bacteria are known to be extremely sensitive to oxygen, it is important that samples which will be used in anaerobic culturing procedures be handled in a manner that minimizes exposure to air. This can be accomplished by extruding subsamples into sterile glass tubes from which the air is replaced quickly with an oxygen-free gas.

Two methods have been utilized for air removal and replacement. In one method the sample tube is closed with a cotton plug and placed in an anaerobic jar from which the oxygen is removed either by catalytic means or by the use of a vacuum pump-replacement gas system (usually oxygen-free nitrogen). In the second method, the sterile glass tube containing the subsample is fitted with a gas-tight rubber septum stopper. A needle is pushed through the septum and the tube is evacuated with a vacuum pump and filled with a sterile, oxygen-free gas such as nitrogen. This process of evacuation and gas replacement should be repeated at least three times.

Samples to be analyzed for parameters such as biomass or viruses require specialized processing procedures which are continually changing as the state of art develops. Because such procedures are rapidly being improved, recommendations of any specific procedure are beyond the scope of this manual.

After a sub-core for microbial analysis has been removed from the parent core, a 10 cm (4 in) length of core material for chemical analysis is obtained. For organic analyses, the sample is extruded directly into a thoroughly cleaned disposable aluminum baking pan, covered tightly with clean aluminum foil, and placed in an insulated polystyrene box containing liquid nitrogen to quick-freeze the sample material. Typical locations for microbial and organic samples in a parent core are shown in Figure 32.

The frozen samples are returned to the laboratory on dry ice, stored temporarily at -45°C in a low-temperature freezer, and freeze-dried as soon as possible in a bulk type freeze dryer. Each sample of dried solids is carefully crushed and mixed to obtain a better degree of homogeneity. These samples are then transferred to thoroughly cleaned 475 ml (16 oz) wide-mouth jars with Teflon lined caps and stored at -45°C until subjected to further processing or analysis.

Samples of dried core material may be subjected to gross organic analysis, such as total organic carbon, without further processing. Samples suitable for more definitive analysis, including identification of individual compounds, are prepared by solvent extraction of the solid samples.

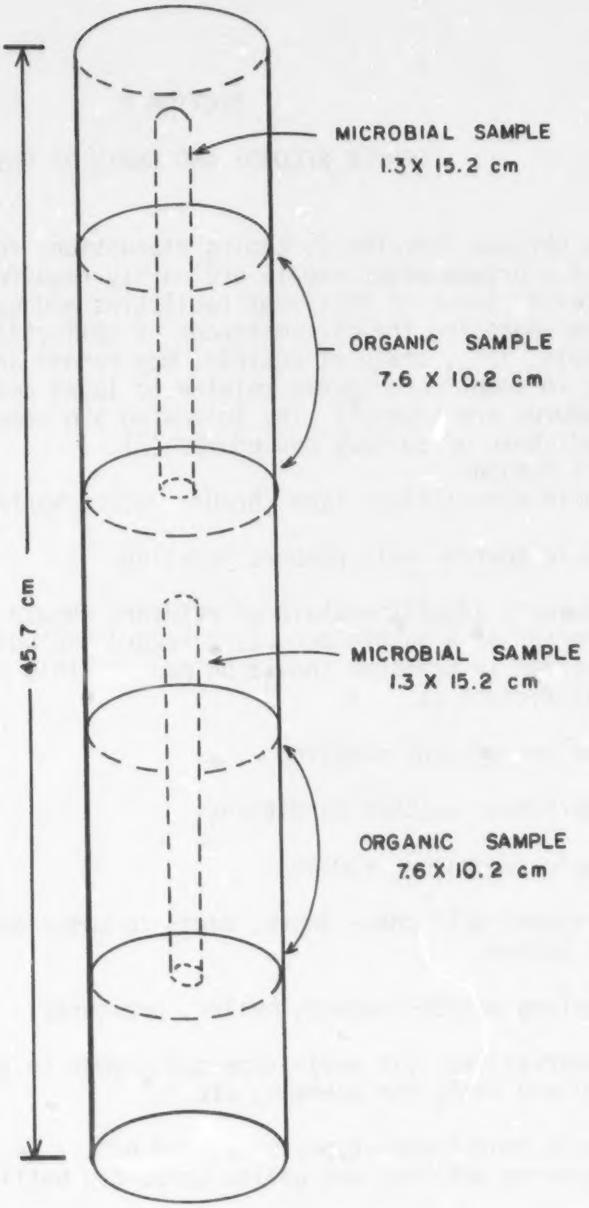

MICROBIAL SAMPLE
1.3 X 15.2 cm
ORGANIC SAMPLE
7.6 X 10.2 cm
45.7 cm
MICROBIAL SAMPLE
1.3 X 15.2 cm
ORGANIC SAMPLE
7.6 X 10.2 cm

Figure 32. Typical Locations for Subsamples (14)

SECTION 8

SAMPLE RECORDS AND CHAIN OF CUSTODY

It is obvious from the foregoing discussions that the collection and analysis of a ground water sample ordinarily requires a substantial investment of resources in terms of equipment facilities and manpower. However, inadequate information regarding the circumstances of collection and subsequent disposition of the sample, i.e., chain of custody, may render any resulting data useless. Especially in sampling programs related to legal actions, proper chain of custody procedures are crucial. The following are some basic guidelines for sample records and chain of custody procedures (2):

Sample Records

- sample description--type (ground water, surface water), volume;
- sample source--well number, location;
- sampler's identity--chain of evidence should be maintained; each time transfer of a sample occurs, a record including signatures of parties involved in transfer should be made. (This procedure can have legal significance.);
- time and date of sampling;
- significant weather conditions;
- sample laboratory number;
- pertinent well data--depth, depth to water surface, pumping schedule, and method;
- sampling method--vacuum, bailer, pressure;
- preservatives, (if any)--type and number (e.g., NaOH for cyanide, H_3PO and $CuSO_4$ for phenols, etc.);
- sample containers--type, size, and number (e.g., three liter glass stoppered bottles, one gallon screw-cap bottle, etc.);
- reason for sampling--initial sampling of new landfill, annual sampling, quarterly sampling, special problem sampling in conjunction with contaminant discovered in nearby domestic well, etc.;
- appearance of sample--color, turbidity, sediment, oil on surface, etc.;

- any other information which appears to be significant--(e.g., sampled in conjunction with state, county, local regulatory authorities; samples for specific conductance value only; sampled for key indicator analysis; sampled for extended analysis; resampled following engineering corrective action, etc.);

- name and location of laboratory performing analysis;

- sample temperature upon sampling;

- thermal preservation--(e.g., transportation in ice chest);

- analytical determinations (if any) performed in the field at the time of sampling and results obtained--(e.g., pH, temperature, dissolved oxygen, and specific conductance, etc.);

- analyst's identity and affiliation.

Chain of Custody

- As few people as possible should handle the sample.

- Samples should be obtained by using standard field sampling techniques, if available.

- The chain of custody records should be attached to the sample container at the time the sample is collected, and should contain the following information: sample number, date and time taken, source of the sample (include type of sample and name of firm), the preservative and analysis required, name of person taking sample, and the name of witness. The prefilled side of the card should be signed, timed, and dated by the person sampling. The sample container should then be sealed, containing the regulatory agency's designation, date, and sampler's signature. The seal should cover the string or wire tie of the chain of custody record, so that the record or tag cannot be removed and the container cannot be opened without breaking the seal. The tags and seals should be filled out in legible handwriting. When transferring the possession of samples, the transferee should sign and record the date and time on the chain of custody record. Custody transfers, if made to a sample custodian in the field, should be recorded for each individual sample. To prevent undue proliferation of custody records, the number of custodians in the chain of possession should be as few as possible. If samples are delivered to the laboratory when appropriate personnel are not there to receive them, the samples should be locked in a designated area within the laboratory so that no one can tamper with them.

- Blank samples should be collected in containers, with and without preservatives, so that the laboratory analysis can be performed to show that there was no container contamination.

- A field book or log should be used to record field measurements and other pertinent information necessary to refresh the sampler's memory in the event he later becomes a witness in an enforcement proceeding. A separate set of field notebooks should be maintained for each survey and stored in a safe place where they can be protected and accounted for at all times. A standard format should be established to minimize field entries and should include the types of information listed above. The entries should then be signed by the field sampler. The responsibility for preparing and retaining field notebooks during and after the survey should be assigned to a survey coordinator or his designated representative.

- The field sampler is responsible for the care and custody of the samples collected until properly dispatched to the receiving laboratory or turned over to an assigned custodian. He must assure that each container is in his physical possession or in his view at all times or stored in a locked place where no one can tamper with it.

- Photographs can be taken to set forth exactly where the particular samples were obtained. Written documentation on the back of the photograph should include the signature of the photographer, the time, date, and site location. Photographs of this nature, which may be used as evidence, should be handled according to the established chain of custody procedures.

- Each laboratory should have a sample custodian to maintain a permanent log book in which he records for each sample the person delivering the sample, the person receiving the sample, date and time received, source of sample, sample number, how transmitted to the lab, and a number assigned to each sample by the laboratory. A standardized format should be established for log-book entries. The custodian should insure that heat-sensitive or light-sensitive samples or other sample materials having unusual physical characteristics or requiring special handling are properly stored and maintained. Distribution of samples to laboratory personnel who are to perform analyses should be made only by the custodian. The custodian should enter into the log the laboratory sample number, time, date, and the signature of the person to whom the samples were given. Laboratory personnel should examine the seal on the container prior to opening and should be prepared to testify that their examination of the container indicated that it had not been tampered with or opened.

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APPENDIX A

SUMMARY OF PROCEDURES BASED ON PARAMETER OF INTEREST

The nature of the pollutant being sampled for is the primary factor determining the type of well and the sampling method recommended for monitoring and investigative sampling. This summary section offers guidelines for sampling procedures to be used for various categories of pollutants. For specific details of each sampling procedure and recommended sample-handling procedures consult the appropriate section in the text, references, and bibliography.

Measurement	Well-Construction	Sampling Method
Physical Properties		
Color	All of the drilling and construction methods described in the test are acceptable. The use of water or drilling mud will not significantly affect the samples if the well is pumped prior to sampling for a sufficient time to clear the well of drilling fluids. This can be determined in the field using a conductivity meter.	All of the methods described in the text are acceptable. The easiest method should be used providing the sampling device is rinsed thoroughly between sampling events. Devices which affect the gas composition of the sample will affect the pH.
Conductance		
Hardness		
Odor		
pH		
Residue		
Filterable		
Non-filterable		
Total		
Volatile		
Settleable Matter		
Temperature		
Turbidity		

Measurement	Well-Construction	Sampling Method
Metals		
Dissolved	All of the drilling and construction methods described in the text are acceptable except bentonite clays or other clay-based drilling muds should not be used if possible. Plastic casing is preferable to metal casing.	All of the methods described in the text are acceptable provided the ground water is not aerated during the sampling. The sampling device should be metal-free and should be rinsed thoroughly between sampling events.
Suspended		
Total		
Mercury		
Dissolved		
Total		
Inorganics, Non-Metallics		
Acidity	All of the drilling and construction methods described in the text are acceptable. The use of water or drilling mud will not significantly affect the samples if the well is pumped prior to sampling for a sufficient time to clear the well of drilling fluids. This can be determined in the field using a conductivity meter.	All of the methods described in the text are acceptable although methods such as bailers, squeeze pumps, and piston pumps which minimize changes in dissolved gas composition of the sample are preferable if the parameters being measured are affected by pH or dissolved gas changes.
Alkalinity		
Bromide		
Chloride		
Chlorine		
Cyanides		
Fluoride		
Iodide		
Nitrogen		
Ammonia		
Kjeldahl, Total		
Nitrate plus Nitrite		
Nitrate		
Nitrite		

Measurement	Well-Construction	Sampling Method
Dissolved Oxygen		
Probe		
Winkler		
Phosphorus		
Ortho-phosphate, Dissolved		
Hydrolyzable		
Total		
Total, Dissolved		
Silica		
Sulfate		
Sulfide		
Sulfite		
Organics - Routine Analyses		
COD	All of the drilling and construction methods described in the text are acceptable, with exceptions noted below.	All of the methods described in the text are acceptable provided the sampling device is rinsed thoroughly between sampling events, with exceptions noted below.
Oil & Grease		
Organic Carbon		
MBAS		

Exceptions: Methods of Appendix B should be used for "Oil and Grease" when a separate organic phase is present in the aquifer. For high sensitivity "Organic Carbon" analyses methods for "Organics" by chromatographic methods, presented below, are preferable.

Measurement	Well-Construction	Sampling Method
Organics - To be determined using high sensitivity analyses by chromatographic methods		
Purgeable (VOA)	Desirable for wells to be constructed without the use of contaminating drilling fluids and casings. Casing in order of preference should be Teflon, stainless steel, steel. If possible, plastic casing should not be used.	Samples to be analyzed for purgeable volatile organics (VOA) should be collected by a glass or Teflon bailer after the well is thoroughly flushed with non-aerating pump. Vacuum and air-lift pumps should not be used. Samples to be analyzed for trace levels of organics should be collected with Teflon or glass systems.
Non-Purgeable		
Microorganisms		
Bacteria	All of the methods described in the text are acceptable with the exception that biodegradable drilling muds such as Revert should not be used. All components of a well-casing, sandpack pump-should be chlorinated after completion and then thoroughly pumped to remove any residual chlorine.	All of the methods described in the text are acceptable if the sampling device can be sterilized before use.
Fungi		
Protozoa		
Viruses		

APPENDIX B

SAMPLING FOR LOW DENSITY, IMMISCIBLE ORGANICS

Low-density, immiscible organics include gasoline and other chemicals and petrochemicals which have specific gravities less than water and which are likely to be present in aquifers as a separate phase because of low solubility in water. These chemicals tend to float on the water surface in a water table environment and commonly occupy the capillary fringe zone above the water table. In a confined aquifer these chemicals are found along the upper surface of the permeable material and also within the overlying confining layer.

WELL CONSTRUCTION

Care must be exercised to insure that the well screen extends significantly into both the water saturated zone and the overlying formation. This design will insure that contaminants in the capillary fringe or overlying aquitard, as well as ground water, enter the well to be observed. A well screen with abundant open area such as a wire-wrapped screen is important in allowing free flow of the petrochemicals into the well.

With the above considerations in mind, nearly any of the drilling methods previously discussed which permits a well of at least 3 inches ID to be constructed is satisfactory.

SAMPLING PROCEDURES

Sampling procedures for low density, immiscible organics differ substantially from those for other pollutants. It is necessary to sample at least two and sometimes three distinct layers or depths within the sampling well.

After the well is initially constructed it should be developed and pumped to remove invaded water, then, it should sit idle for at least several days to allow the water level to fully stabilize and the floating layer of petrochemicals to stabilize.

Measurement of the thickness of the petrochemical layer may then be accomplished by using a water-level indicator gel with a steel tape to determine the depth to the water surface. A weighted float may be used to determine the depth to the top of the petrochemical layer. The difference between these two readings is the thickness of the petrochemical layer. Electric water-level sounders will not work properly for these determinations.

A sample of the floating petrochemicals may then be taken using a bailer which fills from the bottom. Care should be taken to lower the bailer just through the petrochemical layer, but not significantly down into the underlying ground water.

Samples of the ground water at the bottom of the screen and at some intermediate location, such as the mid point of the screen, may also be obtained with a bailer. However, in order to avoid mixing the waters, a separate casing is temporarily lowered inside the permanent well casing. This casing is equipped with an easily removed cap on the bottom so that no fluid enters the casing until it has reached the desired depth for sampling. The cap is then knocked free of the bottom of the casing, allowing water to enter from that specific depth to be sampled by bailer. At significant depths below the petrochemicals several full bailers of water may be withdrawn and discarded before the sample is taken to obtain a fresh formation sample.

Thorough cleaning of the bailer, as previously discussed, is required between sampling events.